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Future Perspectives and Emerging Trends in Nanotechnology for Agricultural Sustainability

A. G. Visaal, B. D. Deepesh, Sujith Yadav and K. K. Sivakumar

Abstract

Sustainable agriculture has become a critical global priority in light of growing food demands, environmental degradation, and climate variability. Nanotechnology has emerged as a transformative force offering innovative approaches to enhance crop productivity, improve resource use efficiency, and mitigate ecological impact. This article examines the latest developments and future perspectives of nanotechnology in agriculture, particularly its role in achieving long-term sustainability. It explores how nanoscale materials and tools are revolutionizing nutrient delivery, pest control, water management, disease diagnostics, post-harvest processing, and genetic interventions. While the promise is significant, the path ahead requires addressing key challenges related to safety, scalability, regulation, and farmer adoption. With the right frameworks and innovations, nanotechnology could be central to building a climate-resilient and food-secure future.

Introduction: Agriculture at a Crossroads

The agricultural sector stands at a pivotal juncture. With the global population expected to surpass 9.7 billion by 2050, traditional farming systems face enormous pressure to increase food output without depleting natural resources. At the same time, these systems must navigate soil degradation, water scarcity, pest resistance, and the unpredictability of climate change. Against this backdrop, nanotechnology offers novel solutions that align productivity with environmental responsibility. Defined as the manipulation and application of materials at the nanometer scale typically between 1 to 100 nanometers nanotechnology enables the development of tools and materials with unpreced-

ented precision, reactivity, and functionality.

Nano-Fertilizers and Precision Nutrient Manage-

ment: One of the most promising areas of nanotechnology in agriculture is the development of nano-fertilizers. These formulations improve nutrient uptake by delivering essential elements directly to the plant root system in a slow and controlled manner. Unlike conventional fertilizers that suffer from leaching, volatilization, and inefficient plant absorption, nano-fertilizers ensure minimal nutrient loss and better yield outcomes. For instance, zinc oxide nanoparticles have demonstrated the ability to boost chlorophyll synthesis and enhance grain formation in crops such as rice and wheat. Chitosan-coated nanoparticles loaded with

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micronutrients provide further precision by releasing their content in response to environmental cues like soil pH or moisture levels.

Next-Generation Pest Management Using Nano-Pesticides:

Another transformative application is the rise of nano-pesticides. Traditional pesticides often pose risks to non-target organisms, contribute to environmental pollution, and promote resistance in pests. Nano-pesticides overcome these limitations by encapsulating active ingredients within nanoscale carriers, protecting them from degradation and enabling targeted, sustained release. For example, silica-based nanoparticles loaded with insecticides are capable of rupturing only when in contact with pest enzymes, thereby sparing beneficial insects. Similarly, silver nanoparticles have shown significant antimicrobial properties, effectively curbing the spread of fungal and bacterial diseases in various crops. These advancements reduce the frequency and volume of pesticide application, leading to both economic and ecological benefits.

Nanotechnology in Water Efficiency and Soil Health:

Water management is another critical area where nanotechnology is beginning to show substantial promise. In regions facing acute water stress, nano-enabled irrigation systems and moisture-retentive soil amendments can drastically improve water-use efficiency. Nanoclays and hydrogel-based formulations have the capacity to absorb water during irrigation and release it gradually over time, reducing evaporation losses and maintaining soil moisture during dry spells. Furthermore, advanced

nano-membranes such as those based on graphene oxide are being integrated into purification systems to filter contaminants from water sources used for irrigation. These membranes can effectively remove salts, pathogens and heavy metals, thereby expanding the usability of brackish or wastewater for agricultural purposes. Photocatalytic nanoparticles like titanium dioxide also offer a sustainable means of disinfecting irrigation water by breaking down organic pollutants and microbes under sunlight exposure.

Early Disease Detection through Nano-Biosensors

Nanotechnology also holds significant potential in disease detection and precision monitoring. Nano-biosensors are being developed to identify plant diseases at early stages by detecting specific biomarkers or volatile compounds released during pathogen attacks. These sensors, often incorporated into handheld devices or soil probes, can alert farmers before symptoms are visible to the naked eye, allowing timely intervention and minimizing crop loss. Some of the most advanced sensor systems can even be integrated into plant surfaces, operating as 'wearables' that transmit data wirelessly about hydration levels, nutrient status, and stress indicators. Combined with artificial intelligence and internet-of-things (IoT) platforms, these nanosensors pave the way for real-time, data-driven farming decisions.

Nano-Packaging and Post-Harvest Innovations:

Post-harvest losses remain a persistent problem in the global food system, particularly in developing

countries. Nanotechnology offers several solutions to improve food preservation and quality during storage and transport. Nanoscale packaging materials with antimicrobial coatings can extend the shelf life of fruits, vegetables, and grains by preventing microbial growth. Additionally, intelligent packaging systems that incorporate nano-indicators change color in response to spoilage or temperature deviations, offering visual cues to handlers and consumers. These innovations not only reduce food waste but also increase food safety and transparency in supply chains.

Gene Delivery and Non-Transgenic Breeding

Tools: Recent advances have also explored the use of nanotechnology in genetic engineering. Conventional plant transformation methods rely on gene guns or bacterial vectors, which can be invasive, time-consuming, and imprecise. Nanoparticles are now being used as carriers to deliver genetic material such as DNA, RNA, or CRISPR components directly into plant cells without causing physical damage. This non-transgenic approach has the potential to develop crops with enhanced drought tolerance, pest resistance, and nutrient content, while also avoiding some of the public and regulatory concerns associated with genetically modified organisms.

Environmental and Safety Concerns: Despite these advancements, several challenges remain. Nanotoxicity is a growing concern, especially regarding the long-term behavior of certain nanoparticles in the soil, water, and food chains. While metal-based nanoparticles like silver and zinc

oxide offer powerful antimicrobial benefits, their impact on beneficial soil microbes, pollinators, and aquatic ecosystems needs careful evaluation. There is also the issue of bioaccumulation, where non-biodegradable nanoparticles could persist in the environment or be absorbed by plants, potentially entering the food chain. To mitigate these risks, researchers are now focusing on biodegradable nanomaterials such as those derived from cellulose, starch, or other natural polymers. These alternatives promise similar functionalities while offering better environmental safety profiles.

Socioeconomic Barriers and Access Inequity:

From a socio-economic standpoint, the cost of developing and deploying nano-agricultural solutions can be prohibitive for smallholder farmers. High production costs, lack of infrastructure, and limited access to credit and training are significant barriers to adoption. Moreover, the regulatory landscape for nanotechnology in agriculture is still evolving. While countries like the United States, European Union, and China have established general nanomaterial safety guidelines, most lack specific regulations for agricultural applications. The absence of standardized testing protocols and labeling requirements makes it difficult to assess product safety and efficacy, hindering widespread commercialization.

Public Perception and Policy Needs: Public perception is another critical factor influencing the adoption of nanotechnology in agriculture. Misinformation or lack of awareness about nanotechno-

logy can lead to skepticism or resistance, particularly when food products are involved. Hence, it is vital to foster transparent communication between scientists, policymakers, farmers, and consumers. Educational campaigns, participatory research, and policy dialogues can help demystify nanotechnology and build public trust.

Emerging Trends in Smart Agriculture: Looking ahead, the future of nanotechnology in agriculture will likely be shaped by its integration with digital technologies. Artificial intelligence and big data analytics, when combined with nano-enabled sensors and devices, can enable predictive models for pest outbreaks, optimize irrigation schedules, and tailor nutrient delivery with unprecedented accuracy. Blockchain technology could be used alongside nano-traceability tags to track the origin, quality, and safety of agricultural products from farm to fork. Biohybrid systems that merge synthetic nanomaterials with biological components such as enzymes or proteins are also under exploration for more adaptive and intelligent agricultural tools.

Global Collaboration and Roadmap Ahead: To fully unlock the potential of nanotechnology, a coordinated global effort is essential. This includes investing in interdisciplinary research, creating farmer-friendly nanoproducts, establishing regulatory clarity, and promoting equitable access across different regions and scales of farming. International collaboration can facilitate knowledge exchange, harmonize safety standards, and encourage technology transfer to low-income countries.

Moreover, inclusive innovation models that involve farmers in the design and testing of nano-agricultural tools will ensure that the solutions developed are both practical and socially acceptable.

Conclusion

Nanotechnology has emerged as a transformative force capable of addressing many of the most pressing challenges in agriculture. From enhancing input use efficiency and reducing post-harvest losses to improving disease diagnostics and enabling precision farming, the applications are wide-ranging and impactful. As research advances, newer forms of biodegradable and intelligent nanomaterials are expected to offer even more sustainable solutions. However, realizing this potential at scale requires addressing environmental risks, establishing clear regulations, ensuring affordability, and building public trust. The future of agriculture depends not just on producing more food, but on producing it smarter, cleaner and more sustainably. Nanotechnology offers a powerful pathway toward that vision, but its success will hinge on responsible development, transparent governance, and inclusive implementation.

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Biopesticides: Harnessing Natural Compounds for Eco-friendly Pest Management

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Abstract

The increasing concerns over environmental degradation and pesticide resistance have led to a surge in interest toward sustainable alternatives to conventional chemical pesticides. Among these, biopesticides derived from natural materials such as animals, plants, bacteria, and minerals offer a promising eco-friendly pest control solution. This article explores the origins, classifications, mechanisms, advantages, and limitations of biopesticides, and examines case studies that illustrate their real-world efficacy. It further outlines regulatory frameworks and global market trends, providing a comprehensive understanding of how natural compounds are reshaping pest management in modern agriculture. The article also discusses future research directions and integration strategies that can enhance the adoption of biopesticides in mainstream agriculture, aligning with global efforts for sustainable farming and food security.

Introduction

Conventional agriculture heavily depends on synthetic pesticides for crop protection. While effective, these chemicals pose significant risks to human health, biodiversity, and the environment. The growing awareness of these issues, coupled with pesticide resistance and regulatory restrictions, has catalyzed the shift toward biopesticides natural, targeted, and biodegradable solutions. Biopesticides are formulated from living organisms or their by-products, offering an environmentally compatible alternative to synthetic chemicals. As agriculture evolves, integrating biopesticides into pest management frameworks is becoming not just an option, but a necessity.

Definition and Types of Biopesticides

Microbial Biopesticides: These are based on bacteria, fungi, viruses, or protozoa. For instance, *Bacillus thuringiensis* (Bt) produces toxins that target specific insect larvae, making it one of the most widely used microbial biopesticides.

Botanical Biopesticides: Derived from plants known to have pest-repelling or insecticidal properties, such as neem (*Azadirachta indica*), pyrethrum (from *Chrysanthemum* spp.), and essential oils like citronella.

Biochemical Biopesticides: These include naturally occurring substances that interfere with pest mating behavior (pheromones), or act as growth inhibitors or repellents.

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RNA-Based Biopesticides: Emerging technologies are leveraging RNA interference (RNAi) to silence essential genes in pests, offering highly specific and non-toxic control methods.

Mechanisms of Action

Biopesticides operate through several mechanisms:

- ✓ Disruption of nerve or hormonal systems (e.g., pyrethrins)
- ✓ Antagonistic interactions with pathogens or pests (e.g., *Trichoderma* spp. against fungi)
- ✓ Induction of plant defense responses (systemic acquired resistance)
- ✓ Feeding deterrence or repellence (e.g., neem extracts)
- ✓ Infection and mortality of specific insect species by viruses or bacteria

Advantages over Synthetic Pesticides

Eco-Friendliness: Biopesticides are biodegradable and generally non-toxic to non-target organisms, including beneficial insects, mammals, and aquatic life.

Target Specificity: Unlike broad-spectrum synthetic pesticides, biopesticides often target only specific pests, reducing collateral damage.

Resistance Management: Biopesticides introduce new modes of action into pest control systems, slowing the development of resistance.

Compatibility with IPM: Integrated Pest Management (IPM) systems emphasize minimal disruption to the ecosystem, making biopesticides ideal for integration.

Challenges in Biopesticide Use

Efficacy and Consistency: Performance can vary due to environmental factors like temperature, humidity, and UV exposure.

Shelf Life and Storage: Many biopesticides are living organisms and require cold storage or special packaging.

Cost and Availability: Initial costs may be higher due to R&D and registration requirements, though long-term costs are competitive.

Regulatory Hurdles: Different countries have varying approval processes that can delay market entry.

Global Market and Regulatory Landscape

The global biopesticide market was valued at approximately USD 4.3 billion in 2021 and is expected to reach USD 10.6 billion by 2030, growing at a CAGR of 10.5%.

Key Regions

North America: Leads in biopesticide production and usage, supported by favorable regulations.

Europe: Strong regulatory backing and consumer demand for organic food drive growth.

Asia-Pacific: Increasing adoption due to the need for sustainable agriculture and high population pressure.

Regulatory Frameworks

USA: Regulated by the EPA under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).

EU: Controlled under Regulation (EC) No. 1107/2009.

India: Biopesticides are regulated by the Central

Insecticides Board & Registration Committee (CIBRC).

Case Studies

Neem-Based Products in India: Neem-based formulations have shown success in controlling aphids, whiteflies, and caterpillars, with minimal environmental impact.

Bt Cotton: Introduced in multiple countries including the US, China, and India, *Bt* cotton expresses the *Bacillus thuringiensis* toxin, reducing the need for chemical sprays and increasing yields.

Viral Biopesticides in Brazil: Use of nuclear polyhedrosis viruses (NPVs) for controlling *Helicoverpa armigera* has reduced pesticide usage and improved crop quality.

Trichoderma-Based Biofungicides: Effective against soil-borne pathogens like *Fusarium* and *Rhizoctonia*, *Trichoderma* spp. are widely used in protected and open-field cultivation.

Biopesticides in Organic Farming

Biopesticides are a cornerstone of organic farming systems. They align with organic standards set by bodies like USDA Organic, EU Organic, and India's NPOP, and help producers meet the rising consumer demand for residue-free produce.

Future Prospects and Research Directions

Genetic Engineering and Synthetic Biology: Next-gen biopesticides will use synthetic biology to enhance traits like stability and specificity, possibly through CRISPR-engineered microbial strains.

Precision Agriculture Integration: Biopesticides combined with drones and IoT systems can be deplo-

yed precisely, reducing waste and improving efficacy.

Public-Private Partnerships: Collaborations can drive innovation, lower costs, and enhance farmer outreach.

Farmer Education: Demonstration trials and government-backed training are essential for large-scale adoption.

Conclusion

Biopesticides represent a transformative shift in pest management, offering a safe, effective, and sustainable alternative to chemical pesticides. Their increasing integration into global agriculture holds the promise of safer food, cleaner environments, and more resilient farming systems. However, overcoming hurdles related to regulation, storage, and awareness remains key to their broader acceptance. With advancing science and supportive policies, biopesticides are poised to become mainstream tools in eco-friendly pest management.

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Nanomaterials for Sustainable Water Management in Agriculture

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Abstract

Water scarcity is a growing challenge that threatens global food security, especially in the face of climate change and rising population demands. Agriculture, being the largest consumer of freshwater resources, must adopt innovative water management strategies to ensure sustainability. Nanomaterials offer transformative solutions across water purification, delivery, retention, and monitoring. This article delves into the types of nanomaterials used in agricultural water management, their mechanisms of action, real-world applications, and potential environmental concerns. It also highlights current research, case studies, regulatory landscapes, and future directions that could redefine the agricultural water paradigm. By harnessing nanotechnology, sustainable agriculture can become more resilient, efficient, and environmentally responsible.

Introduction

Water is essential to agriculture, yet approximately 70% of global freshwater withdrawals are used by the sector. With increasing urbanization, changing weather patterns, and frequent droughts, the demand for more efficient and sustainable water management practices has never been more urgent. Traditional irrigation and purification techniques often suffer from inefficiencies and high energy use. Emerging nanotechnologies promise to overcome these limitations. Nanomaterials, defined as materials with at least one dimension in the 1-100 nm range, exhibit unique physicochemical properties such as high surface area, reactivity, and tunable porosity. These traits make them ideal for targeted applications in water purification, controlled release

of agrochemicals, enhanced soil moisture retention, and intelligent water monitoring systems.

Types of Nanomaterials in Water Management

Metal and Metal Oxide Nanoparticles: These include nanoparticles like titanium dioxide (TiO_2), zinc oxide (ZnO), silver (Ag) and iron oxides (Fe_3O_4 , Fe_2O_3). They are known for their photocatalytic, antimicrobial, and adsorptive properties.

Carbon-Based Nanomaterials

Carbon nanotubes (CNTs): Used in water filtration membranes due to their strength, conductivity, and adsorptive properties.

Graphene and Graphene Oxide: Offer high surface area and excellent mechanical strength for desalination and pollutant adsorption.

Zeolites and Silica Nanoparticles: These porous

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nanomaterials are used for slow-release water systems and nutrient retention.

Nanocomposites

Combining multiple nanomaterials allows for synergistic effects, such as combining silver nanoparticles with carbon nanotubes for antimicrobial water filters.

Applications in Agricultural Water Management **Water Purification and Desalination**

Nanofiltration Membranes: Nanomaterial-enhanced membranes offer superior selectivity and permeability compared to conventional filters. Graphene oxide membranes, for instance, can filter heavy metals, pesticides, and pathogens.

Photocatalysis: Titanium dioxide nanoparticles are widely used in solar-based water treatment systems. When activated by sunlight, they generate reactive oxygen species that degrade organic pollutants and pathogens.

Adsorption Systems: Magnetic nanoparticles coated with polymers can capture arsenic, lead, and fluoride from irrigation water, making them safe for crops and groundwater recharge.

Soil Moisture Retention and Water Delivery

Nanoclays and Hydrogels: Nanoclay-based hydrogels can retain water and release it slowly into the soil, reducing the frequency of irrigation and preventing water runoff.

Smart Delivery Systems: Nanoformulated fertilizers and water-retention polymers can respond to soil pH, temperature, or moisture levels, ensuring water is delivered only when needed.

Wastewater Recycling for Irrigation: Nanomaterials help remove salts, organic matter, and pathogens from treated wastewater, making it suitable for agricultural reuse.

Precision Monitoring: Nano-enabled sensors embedded in soil or irrigation systems monitor moisture levels, salinity, and water flow in real time. This allows data-driven irrigation decisions and prevents overuse.

Mechanisms of Action

Surface Adsorption: Nanomaterials with large surface areas can adsorb various pollutants, including nitrates, phosphates, heavy metals, and pesticides.

Catalytic Degradation: Photocatalytic nanomaterials generate radicals that degrade organic molecules, breaking them down into harmless by-products.

Controlled Release: Nanocarriers encapsulate water molecules and release them gradually depending on environmental triggers such as dryness or heat.

Ion Exchange and Desalination: Some nanomaterials, especially modified zeolites and metal oxides, exchange ions to remove salts and minerals from water used for irrigation.

Benefits of Nanomaterials in Water Management

High Efficiency: Removes pollutants and pathogens with greater accuracy.

Reduced Input Use: Enhances water retention and delivery efficiency.

Energy Savings: Nanotech filtration can operate at lower pressures and energy.

Scalability: Many nanomaterials can be mass-

produced at reasonable costs.

Environmental Safety: Targeted application reduces waste and runoff.

Risks and Environmental Concerns

Nanotoxicity: Some metal nanoparticles, especially silver and zinc oxide, can be toxic to beneficial soil microorganisms and aquatic life if not properly managed.

Soil Accumulation: Persistent nanomaterials may accumulate in the soil and disrupt microbial communities or nutrient cycles.

Regulatory Gaps: Lack of standardized testing and regulation may lead to unmonitored environmental exposure.

Public Perception: Consumer and farmer hesitancy due to unfamiliarity with nanotechnology can slow adoption.

Real-World Case Studies

Graphene Oxide Filters in India: A pilot project in Rajasthan used graphene oxide filters to purify brackish groundwater for drip irrigation. Results showed 80% salt reduction and a 25% increase in crop yield.

Silver Nanoparticle Membranes in Israel: Advanced filtration systems using AgNP membranes helped treat wastewater for irrigation in citrus orchards, reducing microbial contamination significantly.

Zeolite Hydrogels in Sub-Saharan Africa: Smallholder farms used nanoclay-based hydrogels in arid regions, increasing soil water retention by 60% and reducing irrigation frequency by 40%.

Nanobiosensors in California Vineyards: Wireless nanosensors measured soil water potential in real-time, optimizing drip irrigation schedules and saving over 30% water annually.

Policy and Regulatory Landscape

International Guidelines

ISO/TC 229: Provides global standards for nanomaterials.

OECD: Publishes guidelines for safety testing and risk assessment.

National Frameworks

United States: EPA and USDA oversee nanomaterial usage in agriculture.

European Union: REACH Regulation requires disclosure and safety evaluation.

India: National Nanotechnology Mission encourages sustainable applications but lacks specific agricultural guidelines.

Future Directions

Biodegradable Nanomaterials: Developing bio-based nanomaterials such as chitosan or cellulose nanofibers can address concerns about environmental accumulation.

AI and IoT Integration: Combining nanosensors with machine learning can improve irrigation forecasts and identify water stress zones in fields.

Customizable Water Management Platforms: Cloud-based dashboards fed by nano-sensor networks can give farmers real-time updates on field conditions.

Decentralized Water Treatment Units: Nano-enabled portable purification systems powered by

solar energy can provide clean irrigation water in remote rural areas.

Conclusion

Nanomaterials are revolutionizing water management in agriculture by making systems more efficient, targeted, and sustainable. From filtration and purification to moisture retention and smart irrigation, the applications are diverse and impactful. However, for widespread adoption, challenges related to safety, affordability, and regulatory compliance must be addressed. Responsible innovation, interdisciplinary research, and stakeholder collaboration will be critical in leveraging the full potential of nanotechnology for global agricultural resilience.

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Desi Chicken Farming: Tips and Techniques for Healthy and Productive Flocks

Surendra Singh

Desi chicken farming is a popular and profitable venture for many small-scale farmers and backyard poultry enthusiasts. Desi chickens, also known as indigenous or native chickens, are known for their hardiness, disease resistance, and unique flavor. With proper care and management, Desi chickens can thrive and provide a steady source of income and nutrition. Here are some tips and techniques for healthy and productive Desi chicken flocks:

Choosing the Right Breed

Desi chickens come in a variety of breeds, each with its unique characteristics and advantages. Some popular breeds include:

Aseel: Known for its strength, aggression, and fighting ability.

Kadaknath: Famous for its black meat and eggs.

Chittagong: A popular breed in Bangladesh, known for its high egg production.

Pratapdhan: Famous in mewar region for disease resistant.

When choosing a breed, consider factors such as climate, market demand, and your farm's specific needs.

Housing and Infrastructure

Providing adequate housing and infrastructure is crucial for the health and productivity of your

Desi chicken flock. Here are some tips:

- ✓ Build a sturdy and predator-proof coop that protects your chickens from harsh weather conditions and predators.
- ✓ Ensure adequate ventilation and lighting in the coop.
- ✓ Provide enough space for your chickens to move around comfortably.
- ✓ Use dry and clean bedding material, such as straw or sand, to keep the coop clean and dry.

Nutrition and Feeding

Desi chickens are omnivores and require a balanced diet that includes grains, proteins, and vegetables. Here are some feeding tips:

- ✓ Provide a commercial layer feed or starter feed, depending on the age and production stage of your chickens.
- ✓ Supplement their diet with grains, such as oats, wheat, and barley.
- ✓ Offer vegetables, such as leafy greens and root vegetables, to provide essential vitamins and minerals.
- ✓ Ensure access to clean and fresh water at all times.

Health Management

Desi chickens are generally hardy and disease-resistant, but they still require regular health

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checks and vaccinations. Here are some health management tips:

- ✓ Vaccinate your chickens against common diseases, such as Newcastle disease and infectious bronchitis.
- ✓ Monitor your flock regularly for signs of illness or stress.
- ✓ Provide a clean and healthy environment, including regular cleaning of the coop and provision of fresh water and feed.
- ✓ Consult a veterinarian or poultry expert if you notice any health issues.

Biosecurity Measures

Biosecurity is crucial for preventing the spread of diseases and maintaining a healthy flock. Here are some biosecurity measures:

- ✓ Restrict access to your farm, allowing only essential visitors.
- ✓ Use disinfectants and foot baths to prevent the spread of diseases.
- ✓ Keep your farm clean and tidy, including regular disposal of waste.
- ✓ Monitor your flock regularly for signs of illness.

Egg Production and Management

Desi chickens are known for their egg production, and proper management can help increase productivity. Here are some tips:

- ✓ Provide a nesting box for your hens to lay eggs.
- ✓ Collect eggs regularly to prevent breakage and encourage continuous laying.
- ✓ Ensure adequate lighting, as Desi chickens require 14 hours of light per day for optimal egg

production.

- ✓ Monitor egg production and adjust your management strategies accordingly.

Marketing and Sales

Desi chicken farming can be a profitable venture, but marketing and sales are crucial for success. Here are some tips:

- ✓ Identify your target market, such as local consumers, restaurants, or wholesalers.
- ✓ Develop a marketing strategy, including social media, word-of-mouth, and local advertising.
- ✓ Price your products competitively, taking into account production costs and market demand.
- ✓ Ensure quality and consistency in your products to build customer trust and loyalty.

Record Keeping and Financial Management

Record keeping and financial management are essential for the success of your Desi chicken farm. Here are some tips:

- ✓ Keep accurate records of your flock's health, productivity, and financial performance.
- ✓ Monitor your expenses, including feed, vaccinations, and equipment.
- ✓ Develop a budget and financial plan to ensure sustainability.
- ✓ Review your records regularly to identify areas for improvement.

Challenges and Opportunities

Desi chicken farming faces several challenges, including disease outbreaks, market fluctuations and climate change. However, there are also opportunities for growth and development, such as:

- ✓ Increasing demand for organic and free-range chicken products.
- ✓ Opportunities for value-added products, such as eggs and meat.
- ✓ Growing interest in sustainable and backyard poultry farming.

By understanding these challenges and opportunities, you can develop strategies to overcome obstacles and capitalize on market trends.

Conclusion

Desi chicken farming is a rewarding and profitable venture that requires careful planning, management, and attention to detail. By following these tips and techniques, you can build a healthy and productive flock, increase your income, and contribute to sustainable agriculture. Whether you're a small-scale farmer or a backyard enthusiast, Desi chicken farming offers a unique opportunity to connect with nature and produce high-quality.



Summer Livestock Care: Essential Tips for Farmers

Surendra Singh

Introduction

As summer temperatures rise, farmers face significant challenges in maintaining the health and productivity of their livestock. Heat stress can lead to reduced milk production, weight loss, and even death. To ensure the well-being of your animals and the success of your farm, it's crucial to implement effective summer livestock care strategies. Here are some essential tips to help you protect your livestock from the harsh effects of summer heat.

Understanding Heat Stress in Livestock

Heat stress occurs when an animal's body temperature rises above its normal range, causing discomfort, reduced productivity, and even death. Livestock, especially those with dark coats or high metabolic rates, are susceptible to heat stress. Signs of heat stress include:

- ✓ Panting or rapid breathing
- ✓ Drooling or excessive salivation
- ✓ Lethargy or depression
- ✓ Reduced feed intake
- ✓ Increased body temperature

Providing Adequate Shade and Shelter

Shade and shelter are critical components of summer livestock care. Providing adequate shade can reduce the risk of heat stress and heat-related illnesses. Farmers can:

- ✓ Plant trees or install shade cloths to create shaded

areas

- ✓ Build shelters or barns with adequate ventilation
- ✓ Use shade structures specifically designed for livestock
- ✓ Ensure shade areas are well-ventilated and free of drafts

Ensuring Access to Cool Water

Access to cool, clean water is essential for livestock health and productivity. Farmers should:

- ✓ Provide fresh water at all times
- ✓ Use water cooling systems or shade water containers
- ✓ Ensure water troughs are clean and free of contamination
- ✓ Monitor water quality and temperature regularly

Managing Nutrition and Feeding

Heat stress can impact an animal's nutritional needs and feeding behavior. Farmers should:

- ✓ Offer heat-tolerant feed options, such as feeds with higher energy content
- ✓ Adjust feeding schedules to avoid peak heat hours
- ✓ Provide adequate fiber to maintain digestive health
- ✓ Consider using feed additives to help mitigate heat stress

Monitoring for Heat Stress

Regular monitoring is crucial to detect early

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signs of heat stress. Farmers should:

- ✓ Check animals regularly for signs of heat stress
- ✓ Monitor temperature and humidity levels
- ✓ Take immediate action if symptoms occur
- ✓ Keep records of animal health and productivity

Providing Cooling Measures

Cooling measures can help reduce the risk of heat stress. Farmers can:

- ✓ Use misting systems or sprinklers to cool animals
- ✓ Provide cool surfaces for animals to lie on
- ✓ Use fans or ventilation systems to improve air circulation
- ✓ Consider using cooling pads or mattresses

Planning for Emergency Situations

Farmers should have a plan in place for emergency situations, such as heat waves or power outages. This plan should include:

- ✓ Emergency contact numbers for veterinarians and other experts
- ✓ Procedures for providing emergency care and treatment
- ✓ Backup power systems for critical infrastructure
- ✓ Communication plans for stakeholders

Additional Tips for Specific Livestock

Different livestock species have unique needs and requirements. Here are some additional tips for specific livestock.

- ✓ Provide shade and ventilation, and consider using cooling systems like sprinklers or misting systems.

Managing Heat Stress in Different Climates

Farmers in different climates may need to

adapt their summer livestock care strategies to suit local conditions. Here are some tips for managing heat stress in different climates:

Hot and humid climates: Provide extra shade and ventilation, and consider using cooling systems like sprinklers or misting systems.

Hot and dry climates: Provide shade and ensure access to cool water, and consider using cooling systems like fans or ventilation systems.

Temperate climates: Monitor temperature and humidity levels, and provide shade and ventilation as needed.

Conclusion

Summer livestock care requires careful planning, monitoring and management. By implementing these essential tips, farmers can help protect their livestock from the harsh effects of summer heat and ensure a productive and healthy herd.

Turmeric: The Golden Spice in Ayurveda and Modern Healing

Vivek Patidar, Saloni Patel, Vishal Gehlod, Vinay Sharde and Vipul Birla

Abstract

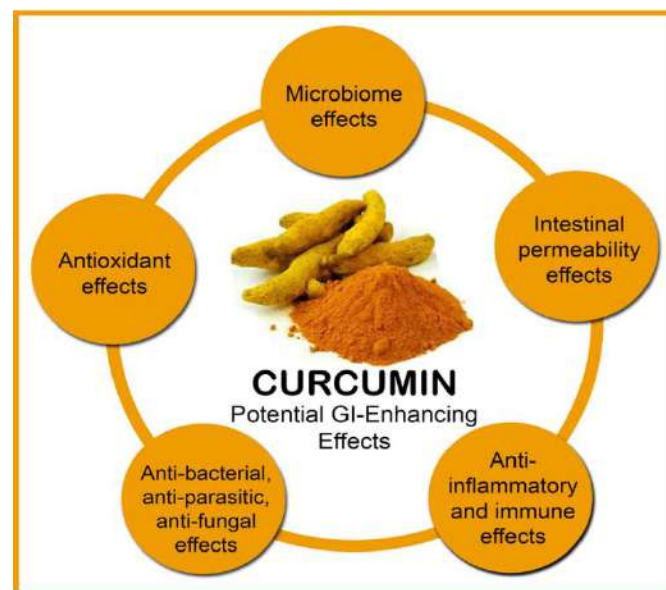
Turmeric (*Curcuma longa*), often known as the “golden spice,” is a powerful herb that has been used for centuries in both Ayurvedic medicine and culinary traditions. This article explores the diverse medicinal properties of turmeric, focusing on its anti-inflammatory, antioxidant, antimicrobial, and digestive health benefits. The active compound in turmeric, curcumin, has been widely studied for its therapeutic effects, and recent scientific findings support many of the traditional uses of turmeric in Ayurveda. Although turmeric offers several health benefits, it also has some potential drawbacks, such as allergic reactions and interactions with certain medications. This article highlights the significant role of turmeric in promoting overall health, while also discussing its limitations and precautions, offering a comprehensive view of how this golden root can be used safely and effectively.

Introduction

Turmeric, a vibrant yellow spice, is an essential ingredient in Indian cuisine, giving dishes their distinct color and flavor. But beyond its culinary use, turmeric has also been cherished for centuries in traditional medicine, particularly Ayurveda. In this ancient system of healing, turmeric is known for its remarkable medicinal properties and is often referred to as a “superfood” for its wide range of health benefits. The active ingredient in turmeric, curcumin, has garnered significant attention from the scientific community, with numerous studies backing up its therapeutic effects. From reducing inflammation to improving digestion, turmeric is more than just a kitchen staple it's a powerful remedy that can promote overall health and well-being.



Anti-Inflammatory Benefits: One of the most widely recognized medicinal properties of turmeric is its ability to reduce inflammation. Chronic inflammation is believed to be the root cause of many health issues, including arthritis, heart disease, and even cancer. In Ayurveda, turmeric has been used for centuries to relieve pain and reduce inflammation.



Medicinal Properties of Turmeric

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This property is primarily attributed to curcumin, which inhibits certain enzymes and molecules that trigger inflammation in the body. For example, curcumin blocks the activity of cyclooxygenase-2 (COX-2), an enzyme responsible for producing inflammation-causing compounds. This makes turmeric a natural and effective option for those suffering from conditions like arthritis and joint pain. Modern scientific research has supported these claims, demonstrating that turmeric can be as effective as conventional anti-inflammatory drugs, but without the harmful side effects.

Antioxidant Power: Turmeric is also renowned for its antioxidant properties. Free radicals are harmful molecules that can damage cells, leading to aging and chronic diseases such as cancer and heart disease. Turmeric's antioxidants, particularly curcumin, neutralize these free radicals, protecting the body from oxidative damage. In Ayurveda, turmeric is often used to "purify" the body, helping it rid itself of harmful toxins and rejuvenate tissues. Scientific studies confirm that curcumin's antioxidant effects can reduce the risk of chronic conditions, slow down the aging process, and boost overall vitality. By protecting cells from oxidative stress, turmeric helps maintain the health of vital organs, particularly the liver and heart.

Antimicrobial Properties: Turmeric's antimicrobial properties make it an excellent natural remedy for fighting infections. In Ayurveda, turmeric has been used to treat a wide range of bacterial, viral, and fungal infections. The antimicrobial effects of turme-

ric are linked to its ability to inhibit the growth of harmful pathogens while promoting the health of beneficial microbes in the body. Recent studies have confirmed that turmeric can fight off various bacterial and viral infections. It can also be applied topically to treat wounds and prevent infection. Whether used in cooking or as a supplement, turmeric helps support the immune system, providing an additional layer of protection against illness.

Digestive Health: In Ayurvedic medicine, digestive health is considered the foundation of overall well-being. Turmeric plays a key role in maintaining a healthy digestive system. It helps stimulate the production of bile, a digestive fluid that aids in the breakdown and absorption of fats. Turmeric's anti-inflammatory properties also soothe the digestive tract, reducing symptoms like bloating, gas, and indigestion. Moreover, turmeric has been shown to help alleviate more serious digestive issues such as irritable bowel syndrome (IBS) and inflammatory bowel disease (IBD). By promoting better digestion and reducing inflammation, turmeric supports gut health and overall digestive function.

The Benefits of Turmeric

Pain Relief: Thanks to its anti-inflammatory properties, turmeric is a natural pain reliever. Whether it's arthritis, muscle soreness, or general aches and pains, turmeric can help alleviate discomfort. Its ability to reduce inflammation in joints and tissues makes it a popular remedy for chronic pain conditions like rheumatoid arthritis and osteoarthritis. In addition to

reducing pain, turmeric may also improve mobility and flexibility in people with joint issues, providing a natural alternative to over-the-counter pain medications.

Cancer Prevention: Turmeric has shown promise in cancer prevention due to its antioxidant and anti-inflammatory effects. Chronic inflammation and oxidative stress are believed to play a significant role in the development of cancer. Curcumin, the active compound in turmeric, has been shown to inhibit the growth of cancer cells, reduce the spread of tumors, and enhance the effectiveness of conventional cancer treatments. While turmeric alone is not a cure for cancer, its inclusion in the diet may help reduce the risk of cancer development and promote overall cancer prevention.

Heart Health: Turmeric is beneficial for heart health in several ways. Its anti-inflammatory properties help reduce the risk of heart disease by lowering inflammation in blood vessels. Additionally, turmeric may help reduce cholesterol levels and prevent the buildup of plaque in the arteries, which can lead to atherosclerosis and heart attacks. Research also suggests that curcumin improves the function of the endothelium, the thin layer of cells that line the blood vessels. By improving endothelial function, turmeric supports healthy blood flow and reduces the risk of blood clots, making it a valuable herb for cardiovascular health.

Liver Detoxification: The liver plays a crucial role in detoxifying the body, and turmeric is a powerful herb for supporting liver health. It enhances bile

production, which helps the liver break down and remove toxins more efficiently. Moreover, turmeric has been shown to protect the liver from damage caused by toxins, alcohol, and certain medications. By promoting detoxification and supporting liver function, turmeric helps the body eliminate harmful substances, promoting overall health and wellness.

Potential Drawbacks of Turmeric

While turmeric offers numerous health benefits there are some potential drawbacks to consider.

Allergic Reactions: Some people may experience allergic reactions to turmeric, including skin rashes, itching, or stomach discomfort. If you have allergies to ginger or other members of the Zingiberaceae family, you may be more likely to react to turmeric.

Drug Interactions: Turmeric can interact with certain medications, particularly blood thinners, such as warfarin. It may also interfere with medications used to manage diabetes or chemotherapy drugs. It is essential to consult a healthcare provider before taking high doses of turmeric, especially if you are on prescription medications.

Conclusion

Turmeric is a versatile and powerful herb with numerous medicinal properties. Its anti-inflammatory, antioxidant, antimicrobial, and digestive health benefits make it a valuable addition to any health regimen. However, it is important to use turmeric responsibly, especially when considering its potential interactions with medications or its effects during pregnancy. By understanding both the

benefits and drawbacks of turmeric, individuals can make informed choices about how to incorporate this golden spice into their daily lives. Whether used in cooking, as a supplement, or as a topical treatment, turmeric remains an invaluable tool for promoting overall health and well-being.

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Nature's Nutrition: Unlocking the Power of Vegetables and Spices

Anurag Sharma, Daksh Dhakad, Ashwin Patidar, Priya Choudhary and Mamta Jamra

Abstract

Vegetables and spices constitute essential components of the human diet, offering a wide range of bioactive compounds with significant health-promoting properties. Vegetables are well-recognized for their contributions of vital micronutrients, dietary fiber, and antioxidants, while spices, despite their minimal caloric content and usage in small quantities, are rich sources of phytochemicals with anti-inflammatory, antimicrobial, and antioxidant effects. This article provides a comprehensive overview of the nutritional and therapeutic roles of vegetables and spices in human health. It discusses their biochemical compositions, physiological effects, contributions to disease prevention, and cultural relevance in traditional dietary patterns. Furthermore, the review addresses contemporary challenges in consumption, the need for policy-driven nutritional education, and the prospects for integrating current scientific evidence into public health strategies. Emphasis is placed on the potential of these natural dietary constituents in promoting sustainable food systems and preventive healthcare.

Introduction

Good nutrition is essential for maintaining health and preventing disease. Among the different types of foods we consume, vegetables and spices are especially important. Vegetables are rich in essential nutrients such as vitamins, minerals, fiber, and antioxidants, all of which help the body function properly and protect against illnesses. Spices, although used in small amounts, contain powerful natural compounds that can reduce inflammation, fight harmful microbes, and support digestion and metabolism. For centuries, vegetables and spices have been key parts of traditional diets around the world. Scientific research is now confirming what many cultures have long believed that these natural foods can play a significant role in preventing and

managing health conditions such as heart disease, diabetes, and even certain types of cancer. Despite their benefits, the intake of vegetables and traditional spices is decreasing in many parts of the world. This is often due to the popularity of fast food and processed meals, which tend to be low in nutrients. This article explores the nutritional value and health benefits of vegetables and spices, their role in disease prevention, their cultural significance, and the need to encourage their use through education and public health efforts.

Nutritional Value of Vegetables

Vitamins and Minerals: Vegetables are dense sources of essential vitamins and minerals that support key bodily functions. Leafy greens like spinach and kale are rich in vitamin K, which supports bone

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health and blood clotting. Carrots provide beta-carotene, a precursor to vitamin A, vital for vision and immune function. Bell peppers and broccoli are excellent sources of vitamin C, an antioxidant that also boosts immunity and enhances iron absorption. Minerals such as potassium, found in potatoes and sweet potatoes, help regulate blood pressure, while magnesium and calcium support bone and muscle function. Dark green vegetables are particularly notable for their iron content, crucial for red blood cell production.

Dietary Fiber: Vegetables are high in dietary fiber, which plays a vital role in maintaining digestive health. Fiber aids in regular bowel movements, prevents constipation, and contributes to a healthy gut microbiome. It also helps regulate blood sugar levels by slowing glucose absorption and reduces cholesterol levels, lowering the risk of cardiovascular disease.

Antioxidants and Phytochemicals: Vegetables are rich in antioxidants such as flavonoids, carotenoids, and polyphenols. These compounds help neutralize harmful free radicals in the body, reducing oxidative stress and inflammation. Cruciferous vegetables like broccoli, cauliflower, and Brussels sprouts contain glucosinolates, which have been linked to cancer prevention. Phytochemicals not only protect cells from damage but also support the immune system and improve metabolic processes. Their synergistic effect with vitamins and minerals makes vegetables essential for long-term health.

The Role of Spices in Nutrition

Concentration of Bioactive Compounds: Spices may be used in small quantities, but they are dense in bioactive compounds that contribute to health. Turmeric contains curcumin, a powerful anti-inflammatory and antioxidant compound. Ginger has gingerol, which aids digestion and reduces nausea. Cinnamon helps regulate blood sugar levels and improves insulin sensitivity. These compounds can modulate biochemical pathways in the body, offering therapeutic benefits that complement modern medicine. The concentration of beneficial phytochemicals in spices can significantly impact chronic disease prevention and treatment.

Antimicrobial and Preservative Properties: Many spices possess natural antimicrobial properties, which have historically been used for food preservation and medicinal purposes. Garlic, cloves, and oregano are known to combat harmful bacteria, fungi, and viruses. These properties not only extend the shelf life of foods but also reduce the risk of foodborne illnesses. In traditional medicine systems such as Ayurveda and Traditional Chinese Medicine, spices are used to prevent infections and support immune function. Modern research continues to explore these benefits, with promising results.

Digestive and Metabolic Benefits: Spices like cumin, coriander, fennel, and black pepper stimulate digestion by enhancing enzyme secretion. They also improve nutrient absorption and reduce bloating and flatulence. Some spices help stimulate appetite, while others regulate metabolism and support weight management. Capsaicin in chili peppers, for example

can boost metabolism and fat oxidation. The thermogenic effect of spices plays a role in energy expenditure and weight control, making them valuable additions to a balanced diet.

Health Benefits and Disease Prevention

Cardiovascular Health: Vegetables, particularly those rich in potassium, fiber, and antioxidants, contribute significantly to cardiovascular health. They help regulate blood pressure, reduce LDL cholesterol, and improve arterial function. Spices like garlic and turmeric have been shown to lower blood pressure and reduce inflammation in blood vessels, thereby reducing the risk of heart disease.

Diabetes Management: Non-starchy vegetables with low glycemic indices help regulate blood sugar levels. Bitter melon and leafy greens are particularly beneficial for people with diabetes. Spices such as cinnamon, fenugreek, and turmeric improve insulin sensitivity and glucose metabolism. Regular consumption of these foods can help manage Type 2 diabetes and prevent its onset in high-risk individuals.

Cancer Prevention: Several vegetables, particularly cruciferous ones, have been studied for their cancer-preventive properties. Compounds such as sulforaphane and indole-3-carbinol promote the elimination of carcinogens and inhibit tumor growth. Spices like turmeric, ginger, and garlic also contain compounds that can induce apoptosis (programmed cell death) in cancer cells and inhibit angiogenesis (formation of new blood vessels that feed tumors).

Cognitive Health: Leafy greens and brightly

colored vegetables provide folate and antioxidants that support brain health and cognitive function. Spices like turmeric (with curcumin) have neuro-protective properties and may reduce the risk of Alzheimer's disease. Studies show that curcumin can cross the blood-brain barrier and reduce plaque buildup associated with neurodegeneration.

Cultural and Culinary Significance

Traditional Diets: Vegetables and spices are central to many traditional dietary patterns known for promoting longevity and health. The Mediterranean diet, rich in vegetables, olive oil, and herbs, is associated with reduced risk of heart disease. Asian cuisines use a diverse array of vegetables and spices that contribute to balanced meals and therapeutic effects. In Indian cuisine, the concept of "Ayurvedic nutrition" emphasizes the use of spices and vegetables tailored to individual body types (doshas) to maintain balance and health. Such practices underscore the deep-rooted connection between food, culture, and health.

Flavor and Satiety: Spices enhance flavor without adding calories or unhealthy fats, making them ideal for healthy cooking. They allow for reduced use of salt and sugar while maintaining taste, which is important in managing hypertension and obesity. Vegetables add bulk to meals, increasing satiety and reducing overall caloric intake. By improving the palatability and nutritional quality of meals, vegetables and spices encourage healthier eating habits.

Environmental and Economic Aspects

Sustainable Nutrition: Vegetables are among the

most environmentally sustainable foods. They require fewer resources (land, water, and energy) to produce compared to animal-based foods. Promoting plant-based diets rich in vegetables can reduce greenhouse gas emissions and support sustainable food systems. Spices are often cultivated in tropical and subtropical regions with relatively low environmental impact. They also support biodiversity and local economies, especially in countries where spice farming is a traditional livelihood.

Accessibility and Affordability: Vegetables are generally affordable and accessible, particularly when grown locally and seasonally. Spices, though sometimes expensive, are used in small quantities and last a long time, making them cost-effective. Promoting home gardening and local markets can further improve access to fresh produce and traditional spices.

Challenges and Future Directions

Declining Consumption: Despite their benefits, vegetable intake remains below recommended levels in many parts of the world. Factors such as urbanization, busy lifestyles, and the rise of processed foods contribute to this trend. Similarly, traditional spice usage is declining in favor of artificial flavorings and salt-laden seasonings.

Food Education and Policy: To address these challenges, food education should emphasize the importance of vegetables and spices from an early age. Public health campaigns, school meal programs, and community initiatives can help promote healthier eating habits. Policies that support local

agriculture, reduce food deserts, and subsidize fresh produce can enhance nutritional equity.

Scientific Research: Ongoing research into the medicinal and nutritional properties of vegetables and spices will continue to unlock their potential. Integrating this knowledge into dietary guidelines and clinical practice could revolutionize preventive healthcare. Nutrigenomics, the study of how food affects gene expression, may offer personalized dietary recommendations in the future.

Conclusion

Vegetables and spices are not just components of a meal they are powerful agents of health, well-being, and disease prevention. Their diverse array of nutrients, bioactive compounds, and therapeutic properties make them indispensable in human nutrition. From bolstering immunity and reducing inflammation to supporting heart and brain health, the benefits of a vegetable- and spice-rich diet are extensive and well-supported by science. As modern diets increasingly lean toward processed and convenience foods, it is more important than ever to recognize the value of these natural, nutrient-dense foods. Embracing vegetables and spices in daily meals is a simple yet profound step toward a healthier, more sustainable future.

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Advancing Livestock Improvement: The Role of Artificial Insemination in Cattle and Buffalo Breeding

Jagdish Chaudhary and Anju Sharma

Abstract

Artificial insemination (AI) is a transformative reproductive technology that has revolutionized livestock breeding, particularly in cattle and buffalo. By enabling the use of superior genetics, AI enhances herd productivity, improves genetic diversity, and reduces the transmission of reproductive diseases. This paper explores the techniques, advantages, and challenges of AI, including semen collection, storage, and insemination methods. Key benefits include increased conception rates, cost-effective herd management, and the ability to utilize high-quality germplasm across distant locations. Despite requiring specialized equipment and skilled technicians, AI's impact on livestock improvement is profound, making it an indispensable tool in modern animal husbandry. The study also highlights optimal timing for insemination to maximize conception rates and discusses ongoing advancements in semen preservation that continue to elevate AI's efficacy.

Introduction

The buffalo (*Bubalus bubalis*) has emerged as a critical livestock species in tropical and subtropical regions due to its ecological adaptability and economic value. Renowned for thriving in harsh environments, buffaloes efficiently convert low-quality roughage into high-value products such as milk and meat, while also serving as a vital source of draft power (Efrain *et al.*, 2016). Compared to cattle, buffaloes exhibit superior metabolic efficiency in milk production, with their milk containing higher total solids 18% to 23% protein, fat, and minerals compared to 13% to 16% in cow milk (Pradhan *et al.*, 1991). These attributes position buffaloes as a

cornerstone of global food security, particularly in regions where sustainable livestock systems are essential (Borghese, 2005). Despite their significance, buffaloes have historically received less attention and research compared to cattle, underscoring the need for advanced reproductive technologies to unlock their full potential. Artificial insemination (AI) represents a transformative technique in livestock breeding, enabling precise genetic improvement and enhanced productivity. In AI, semen containing viable spermatozoa is collected from a male and mechanically introduced into the female reproductive tract at the optimal time under stringent hygienic conditions, resulting in normal

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offspring. The technique, pioneered in 1780 by Italian scientist Lazanno Spallanzani through experiments on dogs, established that the fertilizing capacity of semen resides in the spermatozoa rather than its liquid component. Subsequent research under controlled conditions facilitated the global commercialization of AI, including its widespread adoption in countries like India.

Far from being a mere alternative to natural mating, AI is a powerful tool for livestock improvement, particularly for buffaloes. It allows the dissemination of superior genetic material from high-quality bulls across vast geographical distances, overcoming logistical barriers. Additionally, AI significantly reduces the transmission of genital and non-genital diseases, enhancing herd health and productivity. By integrating AI into buffalo breeding programs, producers can achieve accelerated genetic gains, improved milk and meat yields, and greater sustainability in livestock systems, positioning AI as a cornerstone of modern buffalo husbandry.

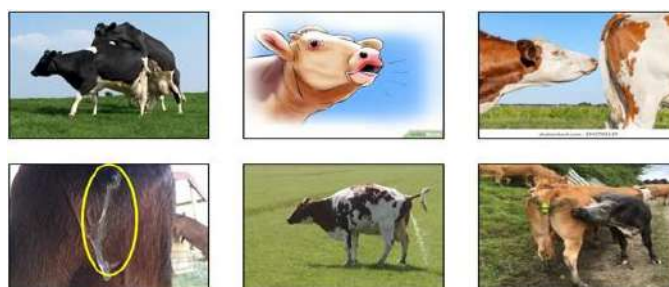
Advantages of Artificial Insemination

Artificial insemination (AI) provides significant advantages that have transformed livestock breeding practices. By eliminating the need to maintain a breeding bull, AI substantially reduces costs related to the bull's upkeep, such as feed, housing, and veterinary care. It also enhances herd health by preventing the spread of genital diseases like contagious abortion and vibriosis, which are common in natural mating. Regular semen evaluation and fertility testing allow for early identification

of subfertile males, improving breeding efficiency. AI enables progeny testing at a younger age, accelerating genetic progress. The preservation of semen allows the use of superior genetics even after a sire's death, and semen can be transported to urban or rural areas, overcoming geographical limitations. AI facilitates safe mating between animals of different sizes without risking injury and is effective for inseminating females that refuse to accept a male during estrus. Additionally, it improves conception rates, supports the use of old, heavy, or injured sires, and ensures accurate breeding and calving records for better herd management.

Symptoms of Oestrus in Cattle

- ✓ Restlessness and increased physical activity.
- ✓ Frequent bellowing or vocalization.
- ✓ Mounting other cows or standing to be mounted.
- ✓ Swelling and reddening of the vulva.
- ✓ Clear, stringy vaginal mucus discharge.
- ✓ Tail raising and frequent tail flicking.
- ✓ Decreased feed intake and milk yield.
- ✓ Frequent urination.
- ✓ Mucus seen on tail, thighs, or hindquarters.
- ✓ Wet or rubbed tail head due to mounting.



Semen Collection Methods and Evaluation

Various methods of collection of semen have been devised from time to time. The older unsa-

tisfactory methods have been gradually replaced by the new modern techniques. There are three common methods.

- ✓ Use of artificial vagina
- ✓ By Electro-stimulation method.
- ✓ By massaging the ampulae of the ductus differences through rectal wall.

The ideal method of semen collection is use of artificial vagina which is safe for sire and the collector also.

Artificial Vagina Method

The artificial vagina has the following parts:

- ✓ A heavy hard rubber 2" lose, open at both ends with a nostonle for air and water in and outlet.
- ✓ Inner sleeve of rubber or rubber liner.
- ✓ The semen receiving cone or rubber cone.
- ✓ Semen collection tube made of glass or plastic graduated in CC and its fraction correct to 0.1 CC

Process

- ✓ Insulating bag: Before using for semen collection all the parts are washed thoroughly and sterilized properly, and assembled as artificial vagina, the rubber liner is inserted into the hose; inverting both ends back by folding back from either side opening, and fastening with rubber bands. Now the space between the hard rubber hose and inner rubber liner forms a water tight compartment. The nostonle at one end of the hose can be fixed.
- ✓ The water jacket of the artificial vagina is filled with hot water at a temperature of 45°C (113°F) by opening the nostonle.
- ✓ The graduated semen collection tube is fixed to

the narrow end of the artificial vagina hose, and fastened by a rubber band.

- ✓ The inner side of the rubber liner on the anterior side of the artificial vagina is lubricated with sterile jelly to a length of 3 to 4 inches.
- ✓ Air is blown through the nostonle into the water jacket, to create pressure in it, and the same is exerted to the rubber linear, to simulate natural vagina.
- ✓ The temperature of the artificial vagina is to be checked, at each collection, and it should simulate natural vagina at mounting time.
- ✓ If it is too cold ejaculate may not be there after a thrust, or even if ejaculate is there; it may be contaminated with urine, and becomes unfit for use.

Semen collection techniques: The cow or dummy is secured in service create. The artificial vagina assembled is held at 45° angle from the direction of penis, and the thrust is at that angle. The artificial vagina is held with the left hand by a right-handed person; and when the bull mounts the cow, the sheath of the bull will be graphed by the operator, directing the gland penis into the artificial vagina, and then the bull gives a thrust to ejaculate. The operator should evince care so as not to touch the exposed past of the penis. After the bull dismounts, the artificial vagina is taken off from penis and the air vent is opened to release the pressure from the jacket.

The water from the jacket is also drained by opening the nostonle. This allows the ejaculate to flow from the cone to the semen collection tube.

The semen collection tube is detached from the cone, plugged with cotton wool, and taken to the laboratory for examination. The rubber cone and the semen collection tube can be protected from external contamination or heat or higher, by covering with an insulation bag with zip.



Electro-ejaculation (EE)

Which involves stimulating ejaculation through electrical impulses. A rectal probe is inserted into the bull or buffalo and controlled electric pulses stimulate the pelvic nerves, causing ejaculation. This method is particularly useful for animals that are not trained to mount or refuse to do so. Although it allows semen collection without prior training, electro-ejaculation may cause discomfort to the animal and the quality of semen collected is often lower than the AV method due to potential contamination.

Massage method: It is another technique where the reproductive organs of the animal are manually stimulated to induce ejaculation. This is done by massaging the seminal vesicles and ampullae through the rectal wall. While this method can be effective for bulls that are not amenable to other methods, the quantity and quality of semen collected are generally lower. It also requires skilled personnel to ensure proper technique and minimize stress to the animal.

Semen Storage: The discovery that bull semen

could be successfully frozen and stored for indefinite periods has revolutionized AI in cattle.

- ✓ In 1949, British scientists discovered that addition of glycerol to the semen extender improved resistance of sperm to freezing. Glycerol acts to remove water from the sperm cell prior to freezing and prevents the formation of cellular ice crystals which would damage the sperm.
- ✓ There are two methods of freezing and storing semen: dry ice and alcohol (-100 degrees F) and liquid nitrogen (-320 degrees F). Liquid nitrogen is preferred because there is no evidence of fertility deterioration with age. Fertility gradually declines in semen stored in dry ice-alcohol.
- ✓ Frozen semen can be stored indefinitely if proper temperature is maintained. Fresh, liquid semen can be successfully stored for 1 to 4 days at 40 degrees.
- ✓ Semen is usually stored in glass ampoules. Other method that appears promising is the French-straw.
- ✓ Artificial coloring is frequently added to semen extenders in order to distinguish one breed from another. Complete identification of the bull is required on each individual semen container.
- ✓ Freezing of semen is done with a special diluent, which has the following composition:
 - ✚ Sodium citrate dihydrate (angular) 2.4 y. 2.0 gm, 8.0 ml 25.0% by volume 50,000 units per 100 ml of semen Fructose Glycerol Egg Yolk Penicillin diluent.

- ✚ Dihydro-streptomycin 50.0 mg per 100 ml of semen diluent.
- ✚ Distilled water double glass distilled 100 ml.
- ✓ The addition of glycerol to the diluent makes the cells more resistant to the rigours of freezing and icy crystals, which form are smaller and smoother thus creating less damage to the spermatozoa. The addition of fructose to the diluent improves sperm resistance to glycerol; and also provides nutrition.
- ✓ Frozen semen is packed in single dose glass vials or plastic straws at +5°C.
- ✓ The final level of glycerol should be 7.0 to 7.6% during the freezing process.
- ✓ The antibiotics are added to inhibit bacteria and to kill pathogenic organisms.
- ✓ The semen to be diluted in such a way that one ml. of extended semen will contain 20 million motile spermatozoa.
- ✓ The semen must be cooled carefully for spermatozoa to remain with life. The final temperature is lowered to -79°C or still lower.
- ✓ Quick freezing is done for a period of 3 to 5 minutes to -75°C with the help of atmosphere created by liquid nitrogen. In the slow freezing technique cooling is done at the rate of 1 °C per minute from +5°C to -15°C. From -15°C to -31°C at the rate of 2°C per minute. From -31°C to -75°C at the rate of 4 to 5°C per minute. Thus, taking 40 minutes in total, further cooling to -96°C can be done quickly as it is not critical after freezing.

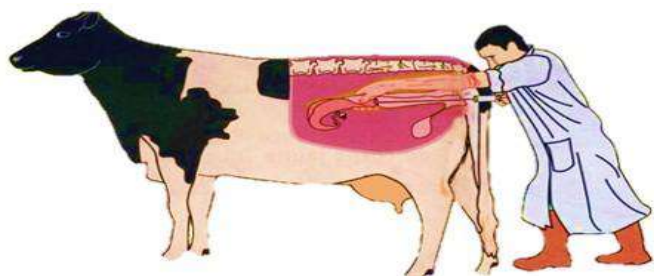
- ✓ Before freezing the diluted semen in equilibrated for 3 to 5 hours or for the best 16 to 20, hours period in refrigerator at 5°C.
- ✓ Liquid nitrogen plays a vital role for storing the frozen semen straws, at a temperature of -196°C for longer periods.

Insemination Methods: There are different methods of insemination in different species of animals i.e. speculum method, vaginal method and recto vaginal method.

Recto Vaginal Method

- ✓ In cattle the safe and best method of insemination is “Recto vaginal method of insemination”.
- ✓ Cow which is in heat is well controlled placing it in a Travis.
- ✓ The inseminator will get ready by wearing a plastic apron, gumboots and gloves.
- ✓ The semen straw after thawing (keeping the semen straw in warm water for a minute to convert the frozen semen into liquid and the sperms become motile) is loaded in a sterilized A.I. gun covered with a plastic sheath.
- ✓ The inseminator will insert the gloved left hand into the rectum after applying the soft soap or other lubricant on the glove and back raked the animal, and the hand is further inserted and will catch hold the cervix through rectal wall.
- ✓ The A.I. gun loaded with semen straw is passed through the vulva to ‘vagina and cervix and observed with the hand in rectum that the A. I. gun reaches the cervix, then the semen is deposited by injecting the gun and after deposit-

ing the semen the gun is removed, the empty straw and sheath are disordered.



Spectrum Method

In this method, spectrum is placed in the vagina of the cow, which provides passage outside to the site of insemination, then inseminating tube is passed through the speculum and semen is deposited at the cervix.

Vaginal Method: Hand is passed through the vagina and the inseminating tube is guided by hand to the site of insemination and semen is deposited. Here there is a risk of contamination and injury of female genitalia.

Timing of Insemination for Maximum Conception: A frequent question concerning AI is: What time during estrus should cows be bred for greatest chance of conception? Since estrus may last from 10 to 25 hours there is considerable latitude in possible time of insemination. Much research work has been conducted on this subject. The studies show that conception rate is lower when cows are bred prior to mid estrus or later than 6 hours after cessation of estrus (standing heat in this case). Maximal conception is obtained when cows are inseminated between mid-estrus and the end of standing estrus, with good results up to 6 hours after estrus. Success in insemination timing is dependent upon a good heat

detection program. In large herds, this means assigning individual responsibility for heat detection and a continued education program for labor. A successful heat detection program and subsequent proper timing of insemination will pay dividends in increasing reproductive efficiency.

Challenges of Artificial Insemination

Artificial insemination (AI) in cattle and buffalo, while highly beneficial, presents several challenges that can impact its effectiveness. The technique requires well-trained operators and specialized equipment, which may not be readily available in resource-limited settings, particularly in rural areas. The process is also more time-intensive than natural mating, demanding precise timing to align with the female's estrus cycle for optimal conception rates. Improper cleaning of instruments or unhygienic conditions during insemination can lead to infections, reducing fertility and negating AI's disease-prevention benefits. Additionally, if the bull's health and semen quality are not thoroughly tested, there is a risk of spreading genital diseases, such as vibriosis, through AI. The procedure further necessitates a deep understanding of reproductive anatomy and physiology, making the operator's expertise critical. Effective heat detection, essential for timing insemination, can be challenging in large herds, requiring consistent monitoring and labor training. These challenges highlight the need for proper infrastructure, training, and adherence to hygienic standards to ensure AI's success in livestock breeding.

Conclusion

Artificial insemination (AI) is a highly effective tool for improving livestock breeding practices, offering numerous advantages over natural mating. It allows for the extensive use of superior genetics, disease control and improved reproductive efficiency. While it requires skilled technicians and specialized equipment, the benefits, such as increased conception rates, better herd management, and genetic advancements, outweigh these challenges. AI has revolutionized modern animal husbandry, particularly in cattle, enabling farmers to enhance productivity while reducing the need for maintaining breeding bulls. As advancements in semen storage and collection techniques continue, AI will remain a cornerstone of livestock improvement efforts.

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Role of Micronutrients in Crop Production

Rahul, Yashpal Choudhary, R. N. Choudhary and Varsha Jeetarwal

Abstract

Micronutrients, though required in trace amounts, play a pivotal role in ensuring optimal plant growth, development, and productivity. These essential elements primarily including iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), boron (B), molybdenum (Mo), and chlorine (Cl) are fundamental to various physiological and biochemical processes within plants, such as enzyme activation, photosynthesis, and nutrient absorption. However, their deficiency or imbalance can lead to significant yield losses and compromised crop quality. It further discusses the common factors contributing to micronutrient deficiencies, such as soil type, pH and intensive cropping practices. Strategies for enhancing micronutrient availability through soil management, foliar applications, and biofortification are also explored. Understanding the role of micronutrients in crop production is vital for developing sustainable agricultural practices that optimize crop yield, improve nutritional quality, and ensure food security.

Introduction

With the population of world growing day by day at a remarkably high rate the fulfilment of their needs is becoming very difficult. Due to this increase in population the cultivable land area is also decreasing day by day. So, to fulfill the food demands of this vast population with limited resources the per unit production of the crops has to be increased and one of the major way to do so is by taking the proper care of their nutrition and following proper management practices. When we talk about the nutrition of the plants both macro and micro nutrients play an important role. The Micro nutrient like other essential nutrients are also important for successful

completion of life cycle of plant, proper working of metabolism of plant and also show deficiency symptoms in plants when present in concentration lower than required. Micronutrients play an important role as catalyst in reactions, ionic balance, synthesis of plant growth hormones, etc.

What are micronutrients?

Micronutrients also known as Trace elements are essential nutrients required by the plants but in smaller concentrations compared to the macronutrients. In plants, micronutrients are vital elements needed in tiny quantities for proper growth, development, and physiological processes. Unlike macronutrients such as nitrogen, phosphorus, and

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potassium, which are required in larger amounts, micronutrients are crucial for plant health even though they are present in minimal amounts. The micronutrients include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn).

Importance of Micronutrients

Enhancing quality and yield is attributed to the role of micronutrients, which function as cofactors for numerous enzymes involved in key metabolic processes within the plant, such as protein and carbohydrate metabolism and the photosynthetic rate. Consequently, this leads to an increase in protein content, total soluble solids (TSS), and other quality parameters, thereby improving overall quality. Additionally, micronutrients like iron are crucial for chlorophyll formation, which boosts photosynthesis and further contributes to increased yield.

Micro nutrients are required throughout the growth cycle



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In legumes, micronutrients such as iron and molybdenum significantly impact nitrogen fixation because they are essential components of nitrogenase enzymes, which aid in the formation of leghaemoglobin, an oxygen scavenger.

The concentration of micronutrients in

planting seeds affects the vigor of the next season's crop. The primary economic benefit of maintaining proper micronutrient levels in a farming operation lies in the enhanced efficiency of macronutrient fertilizer use.

Causes of micronutrient deficiencies

- ✓ Poor soil compaction
- ✓ High soil erosion
- ✓ Improper crop rotation
- ✓ Losses of top soil by erosion
- ✓ Intensive cropping
- ✓ Use of modern-day cultivars
- ✓ Losses of micronutrients through leaching
- ✓ Use of marginal land for crop production
- ✓ Water logged or poorly drained soil
- ✓ High level of other elements

Factors Affecting availability of micronutrients

- ✓ Soil compaction
- ✓ Temperature stress
- ✓ Moisture stress
- ✓ Organic matter
- ✓ Soil pH
- ✓ Soil microbial activity
- ✓ Texture of soil
- ✓ Soil structure

Key Roles of Micronutrients:

Enzyme Activation: Zinc, manganese, and copper act as essential cofactors for enzymes, aiding in important biochemical reactions necessary for plant growth. For example, zinc is important for enzymes involved in protein synthesis and growth regulation (Thapa *et al.*, 2021).

Photosynthesis: Iron, manganese, and copper are crucial for the photosynthetic machinery. Iron is needed for chlorophyll formation, while manganese and copper play roles in the electron transport chain, which is vital for energy production (Wortmann *et al.*, 2019).

Hormone Regulation: Boron is involved in the synthesis and function of plant hormones that are essential for cell division and elongation, promoting proper growth and development (Behera *et al.*, 2019).

Nutrient Transport and Utilization: Molybdenum is essential for nitrogen fixation and assimilation in legumes, helping convert atmospheric nitrogen into a form that plants can use, which is crucial for the growth of leguminous crops (ICAR, 2022).

Disease Resistance: Some micronutrients enhance plants' ability to resist diseases. Copper, for instance, has antimicrobial properties that help prevent infections caused by fungi and bacteria (Kiran, 2018).

Reproductive Development: Boron and zinc are critical for the development of reproductive structures, ensuring proper pollen formation, fertilization, and seed development, thereby directly affecting crop yield (Thapa *et al.*, 2021).

Conclusion

Micronutrients, though needed in small amounts, are vital for crop production because they influence key physiological and biochemical processes in plants. Elements like zinc (Zn), manganese (Mn), copper (Cu), iron (Fe), boron (B),

and molybdenum (Mo) are crucial for enzyme activation, photosynthesis, hormone regulation, nutrient transport, disease resistance, and reproductive development.

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Pearlmillet as Fodder: Strengthening Livestock Systems Amid Climate Challenges

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Abstract

Pearl millet (*Pennisetum glaucum*), a highly resilient and drought-tolerant cereal crop and holds significant potential as a sustainable fodder resource, particularly in regions vulnerable to climate change. Its remarkable adaptability to arid and semi-arid conditions, rapid growth, and high biomass yield make it an essential component of sustainable livestock management systems. As climate variability intensifies, ensuring a consistent and nutritious feed supply for livestock has become a serious concern for agricultural sustainability. Through a comprehensive analysis of its agronomic traits, nutritional value, and climate resilience the critical role of pearl millet in strengthening the sustainability of livestock systems amid evolving climate challenges can be understood.

Introduction

Pearlmillet (*Pennisetum glaucum*), is a drought-tolerant crop species widely grown for both grain and fodder purpose, particularly in arid and semi-arid regions where there is less possibility of other crops to occur. Its ability to adapt in extreme temperatures and low water requirements makes it an important crop for livestock feed, especially in areas with limited water supply (Yadev and Yadev, 2023). Pearl millet is a C₄ plant due to which it is very efficient in photosynthesis and dry matter production even under high-temperature conditions, which further contributes to its resilience in such climates. Fodder Pearlmillet is an important source of nutrition for livestock as it is rich source of protein, fibre and essential minerals providing a well-balanced diet for

animals. Fodder Bajra has the potential to be harvested multiple times in a growing season, ensuring a consistent supply of green fodder throughout the growing period, which is crucial for maintaining livestock productivity, particularly for small-scale farming systems (Maktari and Yemeni 2020). Furthermore, the digestibility of pearl millet fodder increases milk production in dairy animals, thus providing economic benefits to farmers. Its ability to grow in poor soils and its contribution in reducing feed shortages during dry periods makes it a sustainable solution in agricultural systems, especially in regions prone to droughts and harsh environmental conditions. Through the cultivation of fodder pearlmillet the rural communities can improve their livestock feed security, ultimately enhancing

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both agricultural sustainability and rural livelihoods.

Nutritional Value: Fodder pearl millet provides excellent nutrition to livestock, making it an ideal feed choice for the animals. It is particularly rich in crude protein, offering around 8-12%, depending on the growing conditions and stage of harvest. It is also a good source of digestible fiber and energy, supporting the overall health and productivity of livestock. These nutrients help to promote growth, improve in dairy animals, and ensure better weight gain in beef cattle. Additionally, fodder pearl millet contains essential micronutrients like calcium, phosphorus and potassium, which are vital for the health of livestock, ensuring strong bones, efficient metabolism, and proper digestion. All these nutrient rich qualities of fodder pearl millet makes it a suitable fodder source (Kumar and Singh, 2023).



Adaptability and growth: One of the greatest strengths of fodder pearl millet is its ability to thrive well in hot, dry climates where other crops struggle to survive. It requires less water compared to other forage crops, making it ideal crop for regions facing frequent droughts or water scarcity. Its deep root system allows it to access moisture from deeper soil layers, further enhancing its drought resistance as compared to others. Fodder pearl millet also grows quickly, typically reaching maturity in 45 to 60 days, depending on the variety and environmental conditions. It can be harvested multiple times during

the growing season, providing farmers with a consistent source of forage throughout the year. This short growing cycle and ability to regenerate after cutting make it a cost-effective and reliable fodder option for farmers.

Benefits for Livestock and Farmers

Fodder pearl millet offers a range of benefits for both livestock and farmers. For livestock, it provides a nutritionally balanced diet that promotes better health, higher milk yield and faster weight gain. The high digestibility and palatability of the forage ensure that animals consume it readily, leading to more efficient nutrient absorption. For farmers, fodder pearl millet is a low-maintenance crop that requires minimal inputs and care, reducing the overall cost of cultivation. Its drought tolerance ensures that farmers can continue to produce valuable forage even in water-limited conditions, reducing the risk of feed shortages. Furthermore, it is suitable for intercropping with legumes like cowpea, which helps improve soil fertility by fixing nitrogen, contributing to sustainable farming practices.

Harvesting and Use: Fodder pearl millet can be harvested at different growth stages depending on the desired use. For green fodder, it is typically cut when the plants are 45 to 60 days old, just before the flowering stage, when it offers the best combination of protein content and digestibility. Farmers can use the fresh green fodder directly, or it can be conserved as silage for use during the off-season which solves the problem of fodder unavailability at difficult times. The flexibility in harvesting allows farmers to

manage their fodder supply efficiently, ensuring a continuous availability of high-quality feed for livestock (Sannagoudar, 2019).

Conclusion

Fodder pearl millet is an essential crop for ensuring sustainable and nutritious livestock feed, especially in regions with challenging climates. Its high nutritional value, drought resistance, and multiple harvests make it a reliable and cost-effective option for farmers. As livestock farming becomes increasingly important for both food production and rural livelihoods, crops like fodder pearl millet will play a crucial role in meeting the demand for high-quality, sustainable feed options. For farmers looking to improve their livestock's health and productivity while minimizing costs, fodder pearl millet offers an excellent solution. With its ability to thrive in harsh conditions and provide consistent forage throughout the year, this crop is set to remain a staple in livestock farming systems across the world.

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Microbial Consortia in Agriculture

Rahul, Varsha Jeetarwal and R. N. Choudhary

Abstract

Microbial consortia in agriculture represent a transformative approach towards sustainable farming, utilizing the synergistic interactions of diverse microbial species to enhance soil health, promote plant growth and improve crop resilience. These naturally occurring or engineered microbial communities operate through complex ecological interactions, including nutrient cycling, pathogen suppression and stress tolerance enhancement. Recent research has demonstrated the potential of microbial consortia to optimize nutrient use efficiency, reduce reliance on chemical inputs and increase crop yields under variable environmental conditions. This abstract explores the principles, benefits, and challenges associated with the application of microbial consortia in agriculture. It highlights recent advances in metagenomics, synthetic biology, and field applications that are driving the development of effective microbial formulations for diverse crops and agroecological settings. By integrating ancient ecological wisdom with modern scientific innovations, microbial consortia offer a promising path toward resilient, eco-friendly agricultural systems.

Introduction

Microorganisms in the natural world rarely function in isolation. Instead, they often exist in interactive communities known as microbial consortia. These groups of diverse microorganisms work together, often achieving results that would not be possible individually. The study and application of microbial consortia are increasingly important across fields such as agriculture, biotechnology, environmental science, and medicine and their use is increasing day by day.

Understanding Microbial Consortia

A microbial consortium refers to a structured community of multiple microbial species that live

and function together within a shared habitat. These communities are defined by various interspecies relationships, which can range from cooperation and mutual support to competition. When functioning together, consortia frequently exhibit emergent properties, or unique capabilities that arise only through their collective interaction.

Microbial consortia may form naturally in environments like soil, marine ecosystems or animal intestines. Alternatively, scientists can create synthetic consortia in the lab, designing them to carry out specific tasks more efficiently than individual strains (Zou *et al.*, 2015).

Microbial Interactions in Consortia

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Within a microbial consortium, several interaction types can occur:

- ✓ Mutualistic relationships, where different species benefit from one another's presence.
- ✓ Commensal interactions, where one species gains while the other is unaffected.
- ✓ Competitive interactions, where species compete for the same limited resources.
- ✓ Syntrophy, a cooperative process where microbes rely on each other to break down substances which could not be degraded alone.

These interactions are often regulated through molecular signals and metabolic exchanges, creating an intricate web of interdependence.

Practical Applications of Microbial Consortia

Environmental Cleanup: Microbial consortia are frequently used in bioremediation, where complex waste products like hydrocarbons, pesticides and industrial chemicals are broken down. A diverse microbial group is typically more effective than a single strain, as it allows for division of labor and sequential breakdown of contaminants.

Sustainable Agriculture: In farming, microbial consortia contribute to plant health and soil enrichment. Combinations of microbes that fix nitrogen, mobilize phosphorus and protect against pathogens help reduce dependency on chemical fertilizers and pesticides, promoting environmentally friendly agriculture (Kumar, 2020).

Industrial Biotechnology: Microbial consortium are used in industries to convert raw materials into biofuels, chemicals and other valuable products.

The division of metabolic tasks among different microbes enhances overall efficiency and allows for more robust processing (Aguilar-Paredes *et al.*, 2020).

Health and Medicine: In the field of probiotics and gut health, microbial consortia are gaining popularity for their ability to mimic the complexity of the human microbiome. These combinations often perform better than single-strain probiotics in supporting digestion, immunity, and overall health (Gao *et al.*, 2023).

Designing Synthetic Microbial Consortia

Modern biotechnology allows researchers to engineer custom microbial consortia for targeted purposes. Using tools from synthetic biology, microbes can be programmed to perform specific roles, communicate via signaling molecules, and maintain population balance. These engineered systems show promise in areas such as precision medicine, carbon capture, and biodegradable plastic production.

Nevertheless, creating stable and predictable consortia remains challenging. Issues such as imbalance, interspecies competition, and environmental variability must be carefully managed.

Challenges and Prospects

Stability: Achieving long-term balance between species in changing conditions is complex.

Control: Steering microbial behavior and interaction patterns remains a key area of research.

Scalability: Moving from laboratory settings to real-world applications requires careful adaptation and

testing. Despite these obstacles, microbial consortia represent an exciting avenue for scientific and technological advancement. As our understanding deepens and tools improve, the ability to harness and design these microbial communities will likely become a cornerstone of future innovation.

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Barley: A Resilient Grain with Ancient Roots and Modern Promise

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Abstract

Barley (*Hordeum vulgare*) is one of the oldest cultivated crops, with a history spanning over 10,000 years. Its resilience and adaptability have made it a staple across diverse climates and agricultural systems, from the arid regions of the Middle East to the temperate zones of Europe and Asia. As a hardy cereal grain, barley has traditionally been valued for its use in animal feed, brewing, and food production. However, recent advances in agricultural science have reignited interest in barley as a vital crop for sustainable agriculture and human nutrition. This abstract explores barley's historical significance, its diverse uses, and its remarkable resilience to environmental stresses. It highlights ongoing research on barley's genetic diversity, biofortification potential, and climate adaptability, which position it as a critical component of future global food security. By examining its ancient roots alongside modern innovations, this study underscores barley's enduring promise in a rapidly changing world.

Introduction

Barley (*Hordeum vulgare*) is one of humanity's earliest domesticated crops, with archaeological evidence supporting and suggesting its cultivation began over 10,000 years ago in the Fertile Crescent an area covering parts of modern-day countries of Iraq, Syria, Turkey, and Iran. Throughout history, barley has served as a staple food, a basis substrate for alcoholic beverages, a form of animal feed and an important commodity in trade. Today, it remains a vital crop in agriculture and food systems worldwide, valued for its adaptability, nutritional content and diverse applications.

Botanical Characteristics and Cultivation

Barley is a self-pollinating annual grass

belonging to the Poaceae family. It exhibits remarkable versatility and resilience and is able to grow in a range of climatic and soil conditions from semi-arid regions to mountainous areas. Its relatively short growing season and drought resistance make it especially valuable in regions facing water scarcity or erratic rainfall or drought.

There are several classifications of barley, including:

- ✓ Two-row and six-row barley, referring to the arrangement of grains on the central spike.
- ✓ Hulled barley, which retains its tough outer layer, and hull-less (naked) barley, where the outer husk is loosely attached and easily removed during processing.
- ✓ Spring and winter barley, depending on the seas-

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on it is sown.

This diversity enables barley to be tailored for various uses and environments.

Economic and Agricultural Importance

Barley ranks among the top five most produced cereals globally, alongside wheat, rice, maize and sorghum. Major producers of barley include Russia, Germany, France, Canada, and Australia. From an agronomic perspective, barley plays an essential role in crop rotation systems. It helps manage soil fertility, control pests and diseases, and reduce the risk of crop failure in abrupt climatic conditions. Barley's requirements for inputs especially for fertilizers and irrigation making it an attractive option for sustainable agriculture.



Primary Uses of Barley

Human Food Consumption: Although barley is less commonly consumed as a staple food crop compared to wheat or rice, it remains a significant food grain in many parts of the world. Barley grains are processed into products like:

- ✓ Pearl barley (polished to remove the outer layers)
- ✓ Hulled barley (with only the inedible hull removed, retaining more nutrients)
- ✓ Barley flour (used in baking or as a thickener)
- ✓ Barley flakes and grits (for breakfast cereals and soups)

Barley-based dishes are especially common in Tibetan, North African, Middle Eastern, and European cuisines. The grain is also increasingly

featured in health food products due to its high fiber content and glycemic control properties (Healthline, 2024).

Beverage Production: Barley is the primary grain used in malting, a process that prepares the grain for brewing beer and distilling spirits like whisky. During malting, the grain is germinated, dried, and sometimes roasted to produce a variety of flavors and colors essential for alcoholic beverages. The brewing industry accounts for a significant portion of barley demand worldwide (Astute Analytica, 2024).

Animal Feed: A large proportion of the global barley grown in whole world is used as animal feed, particularly for cattle, pigs and poultry. Its high carbohydrate content makes it an efficient energy source and is often processed into pellets or mash for easier digestion (Researchgate, 2016).

Industrial Applications: Barley is also used in the production of starches, sweeteners and bio-based materials. Some cosmetic and pharmaceutical industries utilize barley extracts for their antioxidant and anti-inflammatory properties.

Nutritional and Health Benefits

Barley is grain rich in nutrients, dietary fiber, particularly beta-glucans a type of soluble fiber known to reduce cholesterol levels, improve heart health and support glycemic control. It also provides essential nutrients such as:

- ✓ Vitamin B complex (especially niacin and thiamine)
- ✓ Iron and magnesium
- ✓ Selenium and zinc

- ✓ Antioxidants such as lignans and tocopherols

Barley whole grain has a low glycemic index, making it beneficial for people with diabetes or those at risk of metabolic disorders. Research also suggests that regular barley consumption can improve digestive health, aid in weight management and improve overall gut microbiome balance.

Barley and Sustainable Development

Barley aligns well with sustainable agriculture principles. Its requirement for chemical inputs is less than many other cereal crops and can be grown on marginal lands, reducing pressure on more fertile areas. It also serves as an important rotation crop for preventing soil depletion and reducing disease and pest cycles. In the context of climate change, barley's genetic diversity offers pathways to developing stress-tolerant varieties. Breeding programs are actively working to improve traits such as:

- ✓ Heat and drought tolerance
- ✓ Salinity resistance
- ✓ Disease resistance (e.g., rusts, powdery mildew, and Fusarium)

By focusing on resilient traits, barley is poised to play a critical role in future-proofing food systems against environmental stresses.

Challenges and Opportunities

While barley offers many advantages, it faces stiff competition from crops like maize and wheat, which dominate global food markets. Additionally, modern dietary patterns and food processing trends have contributed to a decline in barley consumption as a staple food.

Nevertheless, growing consumer interest in whole grains, functional foods and plant-based diets is helping revive the market for barley. Innovations in product development from barley-based energy bars to plant-based meat alternatives offer exciting new avenues for consumption. Furthermore, the expanding craft beer and whiskey industries continue to drive demand for high-quality malting barley (Metatech Insights, 2024).

Conclusion

Barley stands as a testament to agricultural resilience and innovation. From ancient civilizations to modern food systems, this grain has evolved to meet the needs of changing societies. With its impressive adaptability, health-promoting qualities and wide range of uses, barley is well-positioned to support both human health and sustainable agriculture in the years to come.

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Smart Irrigation Technologies for Water-Efficient Horticulture Crops

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Introduction

Smart irrigation technologies have emerged as crucial tools for water-efficient horticulture, offering significant benefits in water conservation and crop management. These systems utilize various hardware modules, communication technologies, and machine learning methods to optimize irrigation practices (E G and Bala, 2023). One of the key advantages of smart irrigation controllers is their ability to substantially decrease landscape water applications in high water-use conditions. For instance, in Florida, these controllers have been incentivized by governmental agencies and water utilities to reduce public-supply water demand and conserve water resources (Morera *et al.*, 2015). Studies have shown that both evapotranspiration (ET)-based and soil moisture sensor (SMS)-based smart controllers have been praised by users for saving money and irrigating efficiently. Interestingly, while the performance of smart irrigation technologies has been well-documented, user feedback and adoption factors are equally important. Research indicates that the likelihood of continued use of smart controllers is significantly predicted by users' technical knowledge of the devices and their experience with operational challenges.

This suggests that efforts to promote both initial and long-term adoption should focus on emphasizing economic benefits and disseminating best management practices to facilitate understanding and successful operation (Morera *et al.*, 2015). In conclusion, smart irrigation technologies offer a promising solution for water-efficient horticulture. By leveraging advanced sensors, communication protocols, and data analysis techniques, these systems can significantly reduce water consumption while maintaining or even improving crop yields. However, successful implementation and adoption require not only technological advancements but also user education and support to ensure long-term benefits in water conservation and agricultural productivity.

Overview of Smart Irrigation Systems in Modern Horticulture:

Technological innovations have significantly enhanced water use efficiency in horticulture, addressing the growing concerns of water scarcity and the need for sustainable agricultural practices. Smart irrigation systems, powered by solar energy and equipped with sensors, have emerged as effective solutions for optimizing water utilization in agricultural fields (Bouzguenda *et al.*, 2019).

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These systems use Arduino-based controllers, transmitters, and receivers to measure soil moisture, humidity, and temperature, transmitting data to remote stations for efficient water management. Interestingly, while high-efficiency water-saving technologies in agriculture aim to conserve water, they may paradoxically lead to increased water consumption. This phenomenon, known as the irrigation efficiency paradox, occurs when improved efficiency results in expanded irrigation areas rather than reduced water use (Zhang *et al.*, 2020). To address this issue, stakeholders must implement suitable distribution mechanisms for water-saving gains, improve irrigation water metering, and enhance water-use monitoring. In conclusion, the future of water-efficient horticulture lies in the integration of advanced technologies such as remote sensing, precision irrigation, and data-driven management zones (Silva *et al.*, 2020). These innovations, combined with automated irrigation systems and sensor-based data collection, will be crucial in mitigating the global impacts of irrigated agriculture. By enhancing irrigation efficiency and reducing water consumption, these technologies will play a vital role in ensuring sustainable horticultural practices in the face of increasing water stress and climate change.

Challenges and Solutions in Implementing Smart Irrigation: Smart irrigation systems face several challenges in implementation, but also offer promising solutions for water conservation and agricultural efficiency. One of the primary challenge

is the adoption of new technologies by farmers, especially when transitioning from traditional methods. As highlighted in (Wainaina, 2021), farmers may struggle with the transition to drip irrigation systems, which require new capabilities and understanding. The paper emphasizes the need for policies that consider farmers' abilities to adapt to these technologies (Wainaina, 2021). Additionally, the cost of implementing smart irrigation systems can be a barrier, as mentioned in (Tang *et al.*, 2024), which discusses challenges related to system costs and equipment failures. However, smart irrigation systems also present innovative solutions to water management issues. (Hassan *et al.*, 2024) describes a new localization method for wireless sensor networks in smart irrigation, which can improve the accuracy of node positioning by 19% to 58% compared to existing methods. This enhancement can lead to a potential 28% reduction in water consumption (Hassan *et al.*, 2024). Furthermore, (Yuli *et al.*, 2018) reports that smart irrigation tools can achieve 40% water savings and 20% fertilizer savings compared to conventional systems, demonstrating significant environmental benefits (Yuli *et al.*, 2018). In conclusion, while challenges exist in implementing smart irrigation systems, particularly in terms of farmer adoption and system costs, the potential benefits in water conservation and agricultural efficiency are substantial. Continued research and development in this field, as well as supportive policies and education for farmers, can help overcome these challenges and promote wider

adoption of smart irrigation technologies.

Future Trends and Sustainability in Water-Efficient Horticulture:

Water-efficient horticulture is becoming increasingly important as water resources face intense stress due to climate change, regulations, and competing demands. In the UK, irrigated agriculture is a small but economically valuable water user, with its importance growing due to agricultural intensification and the need to increase domestic food production (Knox *et al.*, 2020). The horticulture sector must transition towards more sustainable agroecosystems to maintain its competitive position. Interestingly, the approach to sustainability in horticulture varies across countries. In the Netherlands, a participatory technology design approach was used to develop scenarios for sustainable production systems, involving stakeholders from research, extension, and the horticultural sector (Blom-Zandstra and Van Keulen, 2008). This process revealed that entrepreneurs are more motivated by short-term gains, necessitating a step-by-step approach to achieving long-term sustainability goals. In conclusion, future trends in water-efficient horticulture will likely focus on balancing economic viability with environmental sustainability. This may involve adopting organic approaches, implementing water recycling systems, and utilizing innovative technologies. The success of these initiatives will depend on stakeholder engagement, aligning long-term sustainability goals with short-term economic interests and adapting strategies to local contexts and needs (Blom-Zandstra and

Keulen, 2008; Knox *et al.*, 2020).

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Protected Cultivation: Enhancing Crop Productivity and Sustainability in Modern Agriculture

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Introduction

Protected cultivation has emerged as a sustainable approach to boost crop yields and quality, offering numerous advantages over traditional open-field farming. This method involves growing crops in controlled environments, such as greenhouses or polyhouses, which allows for better management of environmental factors and resources. Studies have shown that protected cultivation can significantly increase crop productivity and economic returns. It allows for off-season crop production and efficient land utilization, contributing to food security and economic stability for farmers. In conclusion, protected cultivation represents a promising approach for sustainable intensification of agriculture. By providing a controlled environment, it enables farmers to maximize crop yields and quality while minimizing environmental impact and resource use. As global food demand continues to rise, the adoption of protected cultivation techniques, along with other sustainable farming practices, will play a crucial role in ensuring food security and agricultural sustainability (Singh and Sirohi, 2004; Choudhary *et al.*, 2024).

Enhancing Crop Productivity through Greenhouse Technologies

Greenhouse technologies have emerged as a promising solution for enhancing crop productivity while addressing environmental concerns. The highlights the potential of controlled environment agriculture in the UK, where specialized production units for fruits and vegetables can be developed on previously unsuitable sites. These systems can achieve high crop productivity through the use of novel crop science and modern controlled-environment technology, while minimizing environmental impact. While plasticulture has driven increases in crop yield, quality, and value in UK horticulture, it also poses significant environmental challenges. The production and pollution of plastic are considered generational challenges, with agricultural soil being the primary receptor of agriplastic pollution. The impact of microplastics on crop productivity, quality, and human health is an area of ongoing research (Cusworth *et al.*, 2022). In conclusion, the integration of greenhouse technologies offers a promising avenue for enhancing crop productivity while addressing environmental concerns. However, it is crucial to mitigate the adverse effects of agriplastics to fully exploit the potential of plasticulture in enhancing the productivity and positive health impact of horticulture.

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Future research should focus on developing sustainable alternatives to traditional plastics and exploring innovative greenhouse technologies that minimize environmental impact while maximizing crop yields. Sustainable farming practices have shown potential to improve crop quality and yield while addressing environmental concerns. Rebouh *et al.* (2023) demonstrates that intensive cultivation technologies for winter wheat, combined with remote sensing data, can enhance both yield quantity and grain quality. The highly intensive cultivation technology (CT3) increased yield by 3 t ha⁻¹ and produced superior grain quality compared to the basic technology (CT1). Remote sensing indices, particularly the Green Chlorophyll Index (GCI), showed high performance in predicting crop yield ($r = 0.98$), while SAVI and NDVI were effective in predicting protein and gluten content ($r = 0.96$).

Montemurro and Maiorana (2015) presents a contrasting perspective, highlighting the positive role of conservative agricultural practices. The study found that crop rotation with leguminous crops improved wheat yield by 6.47% compared to continuous cropping, increased grain protein content by 5.88%, and reduced the productivity gap between conventional and conservative treatments. However, the effects on soil fertility were less pronounced, with only minor differences in total nitrogen values observed at the end of the study. Both intensive and conservative approaches can contribute to improved crop quality and yield, depending on the specific context and management practices employed.

The integration of remote sensing technology, as demonstrated in Rebouh *et al.* (2023), can provide valuable insights for precision agriculture and optimize management practices. However, the long-term sustainability and environmental impacts of these approaches should be carefully considered when implementing agricultural strategies.

Economic and Environmental Benefits of Protected Cultivation

Protected cultivation offers significant economic and environmental benefits for agricultural production, as evidenced by several studies. From an economic perspective, protected cultivation can be highly profitable. In Maharashtra, India, the cultivation of flowers and vegetables under protected conditions showed higher gross returns (250%) and net returns (190%) compared to open cultivation (Pachiyappan *et al.*, 2022). Similarly, organic wheat cultivation in Central Europe was found to be the most profitable farming system (Jelínková *et al.*, 2016). Protected cultivation also has the potential to generate employment, utilize land efficiently, and enhance exports (Pachiyappan *et al.*, 2022). Environmentally, protected cultivation can contribute to sustainability and reduced environmental impact. Organic farming of wheat and oat in Central Europe resulted in 8.04% and 15.46% lower greenhouse gas emissions, respectively, compared to conventional farming (Jelínková *et al.*, 2016). In Ireland, industrial hemp cultivation for CO₂ sequestration showed potential to remove between 5,470 and 24,068 tonnes of CO₂ in 2019 alone (Madden *et al.*, 2022).

Additionally, the use of plant-based amendments in protected cucumber cultivation effectively managed root-knot nematodes while improving soil health (Dhillon *et al.*, 2022). In conclusion, protected cultivation offers a promising approach to sustainable and economically viable agricultural production. It can increase profitability, reduce environmental impacts, and contribute to climate change mitigation. However, careful management is necessary to balance economic gains with potential environmental costs, as seen in the case of greenhouse vegetable cultivation in East China (Qiu and Wu, 2021).

Future Prospects and Challenges in Protected Farming Systems

Protected farming systems, such as urban horticulture and vertical farming, are emerging as crucial components of sustainable agriculture. These systems offer promising solutions to address food security challenges in densely populated urban areas while reducing environmental impacts (Kouloumprouka Zacharaki *et al.*, 2024). One of the key prospects for protected farming systems is the cultivation of high-value crops like strawberries in urban environments. This approach promises year-round fruit availability, reduced reliance on imports, lower food miles, and improved self-sufficiency. Additionally, it can provide employment opportunities and promote a sense of community in urban areas (Kouloumprouka Zacharaki *et al.*, 2024). However, several challenges need to be addressed for the successful implementation of protected farming

systems. One major obstacle is the lack of specialized knowledge among new urban farmers, particularly regarding complex perennial crops like strawberries. Key areas of concern include plant physiology, pathogen management, propagation material selection, fertigation, pollination, and environmental requirements. To overcome these challenges, knowledge exchange between commercial rural producers and urban growers is essential (Kouloumprouka Zacharaki *et al.*, 2024). In conclusion while protected farming systems offer significant potential for sustainable urban agriculture their success depends on addressing the knowledge gap and technical challenges faced by urban farmers. Collaborative efforts between experienced commercial growers, researchers, and urban farmers will be crucial in developing effective strategies for implementing these innovative farming systems in urban environments.

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Synergistic Effects of Weed Control and Nitrogen Management on Crop Productivity in Semi-Arid Regions

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Abstract

Semi-arid agriculture faces significant challenges, including climate change, water scarcity, and weed management. Integrated weed management (IWM) approaches combining multiple strategies offer a promising solution. Cover crop residues and abrasive weeding paired with plastic mulches can effectively suppress weeds while increasing crop nitrogen uptake and yields. However, complex interactions between cover crop species and their impacts on weed dynamics must be considered. Weed control is critical for maintaining crop yield and quality, especially for intra-row weeds in cereal crops. Nitrogen fertilization can boost crop quality parameters like protein content but may also shift weed community composition if not carefully managed. Sustainable agricultural practices, such as conservation tillage, crop residue management, crop diversification, cover cropping, and livestock integration, can improve crop productivity and water use efficiency in semi-arid regions.

Challenges of semi-arid agriculture and the need for integrated weed management

Semi-arid agriculture faces significant challenges, including climate change, water scarcity, and weed management. Climate change poses a threat to food security and livelihoods of smallholder farmers in semi-arid regions. Water availability for crop production is rapidly declining, driving substantial changes in cropping systems, including transitions from irrigated to dryland cropping. Weed management is a particular challenge in semi-arid agriculture. Traditional weed control methods can be costly, economically damaging, and laborious, with variable long-term success. Several weed species have developed resistance to various herbicide modes of action,

further complicating management efforts (Roberts and Florentine, 2024). In pulse production in the northern Great Plains, limited weed control tools present a significant challenge. Integrated weed management (IWM) approaches are crucial for addressing these challenges. IWM combines multiple strategies, including cultural, mechanical, biological, and chemical methods. For example, in cranberry cultivation, proper site and cultivar selection, good drainage, rapid vine establishment, and hand weeding are as important now as when the industry first started. Soil-applied residual herbicides are an important component of IWM programs in pulse crops. Semi-arid agriculture requires a holistic approach to address its challenges, particularly in weed management. Integrated weed management,

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combining various strategies and technologies, offers a promising solution. However, successful implementation depends on considering the broader systemic complications, including social norms, institutions, and government policies (Thierfelder *et al.*, 2024).

Synergistic effects of integrated weed management and nitrogen on nutrient dynamics

Integrated weed management (IWM) strategies combining cover crops, abrasive weeding, and nutrient management can have synergistic effects on weed suppression and crop productivity. Cover crop residues suppress weed germination and biomass production through allelopathy and changes in nutrient availability (Mckenzie-Gopsill and Farooque, 2023). When abrasive weeding is paired with plastic mulches, it can reduce in-row weed density by up to 87% while increasing crop nitrogen uptake and yields (Braun *et al.*, 2019). Interestingly, the addition of legumes like field pea to cover crop mixtures can have both synergistic and antagonistic effects. While pea enhanced biomass production of phacelia, it decreased weed suppression by buckwheat by 8%. This highlights the complex interactions between cover crop species and their impacts on weed dynamics. IWM approaches integrating mechanical, cultural, and nutrient management tactics can effectively suppress weeds while optimizing crop nutrition. However, careful consideration must be given to potential trade-offs and synergies between different management components (Mckenzie-Gopsill and Farooque, 2023).

Impact of weed control and nitrogen levels on crop quality and marketability

The impact of weed control and nitrogen levels on crop quality and marketability varies depending on the specific crops and management practices used. In cereal crops, weed control through inter-row hoeing can be highly effective, but intra-row weeds can still significantly impact crop yield and quality (Melander and Mccollough, 2020). For example, just 10 intra-row plants m⁻² of the surrogate weed *Sinapis alba* reduced grain yields by 7-14% in spring barley and 7-32% in spring wheat. Barley was generally more effective than wheat at suppressing intra-row weeds and limiting yield losses. Nitrogen rates (50 vs 100 kg NH₄-N ha⁻¹) did not consistently affect crop or weed parameters in this study. Nitrogen availability can influence weed-crop competition dynamics (Jäck *et al.*, 2021). Highly N-responsive weeds like *Chenopodium album* accumulated more biomass and N than less responsive weeds when fertilizer was applied. This suggests fertilizer application could shift weed community composition over time towards more nitrophilic species. Interestingly, fertilizer supply favored *C. album* growth but not crop growth in this study. In wheat production, both grain yield and protein content varied over the long-term, likely due to rainfall patterns (Seepamore *et al.*, 2020). Grain yield increased slightly with higher N application rates, while protein content increased significantly. Tillage intensity also increased both yield and protein content.

Proper nitrogen management appears important for optimizing both wheat yield and quality parameters like protein content that impact marketability. Effective weed control, especially of intra-row weeds, is critical for maintaining crop yield and quality. While nitrogen fertilization can boost crop quality parameters like protein content, it may also shift weed community composition if not carefully managed. Integrating cultural practices like tillage and crop rotation with targeted fertilizer and weed management appears necessary to optimize both crop productivity and quality in cereal systems.

Sustainable practices and future directions for improving crop productivity in semi-arid regions

Sustainable agricultural practices play a crucial role in improving crop productivity and water use efficiency in semi-arid regions. Conservation tillage, crop residue management, crop diversification, cover cropping, and livestock integration have been shown to increase soil organic carbon storage, water infiltration, soil microbial activities, and water use efficiency while decreasing nitrogen fertilizer inputs compared to conventional systems (Nilahyane *et al.*, 2023). These practices are particularly important in areas facing water scarcity and soil degradation. Interestingly, farmers' preferences for sustainable agriculture practices (SAPs) vary depending on their crop types and local conditions. In northwest China, both grain and cash crop farmers showed strong preferences for using organic fertilizers and improving irrigation practices. However, cash crop farmers also preferred cover

crop-related practices, while least preferring long-term fallows (Nong *et al.*, 2020). This highlights the importance of tailoring sustainable practices to specific farming contexts and considering farmers' perspectives in implementation strategies. In conclusion, adopting a combination of soil and water conservation practices can enhance soil health and sustainability in dryland or limited-irrigation agriculture in semi-arid regions (Nilahyane *et al.*, 2023). Future directions should focus on developing region-specific strategies that consider local climate projections, farmers' preferences, and the potential for integrating multiple sustainable practices. Additionally, policymakers and stakeholders should work together to devise effective strategies to address climate change impacts on agriculture and encourage the adoption of sustainable practices (Rudraswamy and Umamahesh, 2024).

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Farm Ponds as Sustainable Water Management Solutions in Rajasthan's Agriculture

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Abstract

Farm ponds have emerged as a promising water management strategy in Rajasthan, India, contributing to sustainable agricultural practices and water conservation in the arid region. This study explores the importance, benefits, and challenges of implementing farm ponds in Rajasthan's agricultural landscape. Geospatial tools and multi-criteria decision analysis were employed to identify suitable locations for rainwater harvesting structures, including farm ponds, in the Gambhir watershed. The results revealed that 13% of the total area was very highly suited for these structures, while 19% was highly suitable, with runoff being the prime determining factor. Farm ponds not only serve as water storage facilities but also contribute to improving biodiversity and ecosystem functions in agricultural landscapes. However, the implementation of farm ponds in Rajasthan faces challenges, such as the upfront construction costs and farmers' lack of resources. Proper implementation of legislative provisions and increased awareness among stakeholders can support the successful implementation of farm ponds in Rajasthan, leading to improved water availability, crop yields, and overall ecosystem health.

Introduction

Farm ponds have emerged as a significant water management strategy in Rajasthan, contributing to sustainable agricultural practices and water conservation. The construction of these ponds is crucial for rainwater harvesting (RWH), which is considered one of the most effective strategies for water management in areas facing water scarcity (Gavhane *et al.*, 2023). In Rajasthan's Gambhir watershed, a study using geospatial tools and multi-criteria decision analysis identified suitable locations for RWH structures, including farm ponds. The research revealed that 13% of the total area was very

highly suited for RWH structures, while 19% was highly suitable. Runoff was found to be the prime factor in determining the location of these structures (Gavhane *et al.*, 2023). The study suggested that 25 farm ponds could be constructed at identified locations in the watershed, along with other RWH structures like check dams and percolation ponds. Farm ponds in Rajasthan not only serve as water storage facilities but also contribute to improving biodiversity and ecosystem functions in agricultural landscapes. As observed in other regions, these ponds can maintain high nutrient levels and support rapid vegetation establishment, potentially increas-

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ing species diversity (Choi *et al.*, 2021). It's important to note that pond management practices can significantly affect biodiversity, as seen in studies on odonate species richness in farm ponds (Chien *et al.*, 2019). Farm ponds in Rajasthan represent a promising solution for sustainable agriculture, addressing water scarcity issues while potentially enhancing biodiversity. Their implementation, guided by scientific analysis and proper management practices, can revolutionize agricultural practices in the region, leading to improved water availability, crop yields, and overall ecosystem health.

Farm ponds play a crucial role in agricultural water management, particularly in arid and semi-arid regions like Rajasthan. These small water harvesting structures collect and store rainwater runoff, providing a valuable water source for irrigation during dry spells (Zongo *et al.*, 2022). In Rajasthan's rainfed ecosystem, farm ponds can help address soil erosion and water scarcity challenges that impact crop production (Rashmi *et al.*, 2020). Farm ponds offer multiple benefits beyond just water storage. They can reduce soil loss by up to 29% and runoff by 26% when combined with other conservation practices like applying gypsum, crop residues, and farmyard manure (Rashmi *et al.*, 2020). This integrated approach not only conserves soil and water but also improves crop yields and farm profitability. Additionally, farm ponds can serve as a buffer against climate variability, allowing for supplemental irrigation during dry periods and

potentially meeting the cereal needs of 17 people per month (Zongo *et al.*, 2022). In conclusion, farm ponds represent a sustainable agricultural practice that can significantly enhance water availability, soil conservation, and crop productivity in Rajasthan's challenging agricultural landscape. Their implementation, along with other resource conservation techniques, offers a promising strategy for improving food security and farm incomes in the region's rainfed farming systems.

Farm ponds as a sustainable water management solution in arid regions

Farm ponds have emerged as a promising sustainable water management solution in arid regions, offering multiple benefits for agricultural productivity and environmental conservation. These water harvesting structures collect and store rainwater, providing a crucial water source for domestic and agricultural use in water-scarce areas (Gregson *et al.*, 2022). In arid and semi-arid regions, farm ponds can help address the challenges of water scarcity and declining groundwater availability (Nilahyane *et al.*, 2023). They serve as an effective tool for improving water use efficiency, enhancing soil health, and conserving water in the soil profile (Nilahyane *et al.*, 2023). By collecting rainwater, farm ponds reduce dependence on groundwater resources, which is particularly important in regions facing rapid groundwater depletion. However, the management of farm ponds requires careful consideration of water quality and potential health risks. A study in Kenya revealed that water in these

ponds may become hypoxic or anoxic, potentially impacting crop yield and viability if used for irrigation. The presence of opportunistic pathogens like *Mycobacterium fortuitum* in pond water highlights the need for proper water treatment before use (Gregson *et al.*, 2022). To address these challenges, low-cost management practices can be implemented to improve water quality and remove pathogens, thereby enhancing the overall sustainability and effectiveness of farm ponds as a water management solution in arid regions. Farm ponds offer a sustainable approach to water management in arid regions, contributing to improved agricultural productivity and water conservation. Their successful implementation requires careful management and monitoring of water quality to maximize benefits and minimize potential risks. Integrating farm ponds with other soil and water conservation practices can further enhance the sustainability of agriculture in water-limited environments (Nilahyane *et al.*, 2023).

The economic and environmental benefits of farm ponds for farmers

Farm ponds offer significant economic and environmental benefits for farmers, while also presenting some challenges in implementation, particularly in regions like Rajasthan. Farm ponds provide crucial water storage for irrigation, helping farmers cope with dry spells and water scarcity. In Burkina Faso, supplemental irrigation from farm ponds allowed farmers to meet the monthly cereal needs of at least 17 people and generated additional gross margins of around \$309 compared to no irriga-

tion (Zongo *et al.*, 2022). Farm ponds also contribute to sustainable agriculture by reducing pressure on other water sources. In Taoyuan County, existing farm ponds could irrigate 6.70-10.50% of the total agricultural area, lessening the burden on the Shimen Reservoir. However, implementing farm ponds faces challenges, especially in arid regions like Rajasthan. Farmers there experience higher degrees of risk compared to more irrigated areas like Haryana. Key challenges include the upfront construction costs and farmers' lack of resources. To overcome these, subsidies or credit policies may be necessary to facilitate adoption of supplemental irrigation in Sahelian countries (Zongo *et al.*, 2022).

Challenges and solutions in implementing farm ponds in Rajasthan

Farm ponds in Rajasthan face several challenges in implementation, but also offer potential solutions for water management and agricultural sustainability. A study conducted in the Jodhpur district of Western Rajasthan revealed low awareness among stakeholders regarding the prevention, detection, diagnosis, and rehabilitation of silicosis, a major occupational health hazard in mining areas (Chaturvedi *et al.*, 2022). This lack of awareness extends to the implementation of farm ponds as well. One of the main challenges in implementing farm ponds is the need for robust enforcement in mining units and unregistered mining activities, which hinder the detection of silicosis cases and potentially impact water resources (Chaturvedi *et al.*, 2022). Additionally, the migration of mineworkers poses

difficulties in tracking and managing water resources effectively. However, farm ponds can be a solution to water scarcity issues in the region. A study in the Gambhir watershed of Rajasthan identified suitable locations for rainwater harvesting (RWH) structures, including farm ponds, using geospatial tools and multi-criteria decision analysis (Gavhane *et al.*, 2023). The study revealed that 13% of the total area was very highly suited for RWH structures, while 19% was highly suitable. In conclusion, while challenges exist in implementing farm ponds in Rajasthan, they offer significant potential for water management and agricultural sustainability. The use of geospatial tools and multi-criteria decision analysis can help identify suitable locations for farm ponds (Gavhane *et al.*, 2023). Furthermore, proper implementation of legislative provisions and increased awareness among stakeholders can address the challenges faced during the prevention, detection, diagnosis, and rehabilitation of workers affected by mining activities, which in turn can support the successful implementation of farm ponds (Chaturvedi *et al.*, 2022).

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Biochar as Sustainable Soil Management: Effects on Soil Fertility and Agricultural Productivity

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Abstract

Biochar, a carbon-rich material produced through pyrolysis of organic matter, has emerged as a promising soil amendment for enhancing soil health and agricultural productivity. This review explores the effects of biochar application on soil properties, nutrient retention, and crop performance in various agricultural systems. Studies have demonstrated that biochar can significantly improve soil physicochemical properties, such as pH, organic carbon content, cation exchange capacity, and water retention. These improvements contribute to enhanced nutrient availability and retention, promoting crop growth and yield. However, the effectiveness of biochar varies depending on factors such as soil type, biochar properties, and application rates. Sandy soils tend to exhibit more pronounced benefits from biochar amendments compared to clay soils. The pyrolysis temperature used in biochar production also influences its performance, with higher temperatures resulting in improved soil fertility and herbicide sorption. While biochar shows great potential as a sustainable solution for improving soil health and fertility, its effects can be context-dependent. Further research, particularly long-term field studies, is needed to optimize biochar use for different soil types and cropping systems. This review highlights the importance of considering specific soil and biochar characteristics when implementing biochar-based strategies for sustainable agriculture.

Introduction

Biochar, a carbon-rich material produced through pyrolysis of organic matter, has emerged as a promising soil amendment for enhancing soil fertility and agricultural productivity. Research has shown that biochar application can significantly improve soil properties, including pH, nutrient content, and microbial activity (Alkharabsheh *et al.*, 2023). A study in Coastal Kenya reported that *Prosopis juliflora* biochar application at 7.5 t ha⁻¹

increased soil pH by 21%, total nitrogen by 32%, and available phosphorus by 264% compared to untreated soil. The effects of biochar on soil health can vary depending on the soil type and biochar properties. A comparative study found that biochar amendment was more beneficial in sandy soil than in clay soil, with the maximum crop yield increase observed in 100% sand + biochar treatment. The method of biochar application can influence its effectiveness. Composted biochar has been shown to

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be more beneficial than mixing biochar with compost, particularly in terms of improving soil fertility and mitigating negative effects associated with pure biochar application (Mikajlo *et al.*, 2024).

Biochar and Soil Health

Biochar has been shown to have significant positive effects on soil health and fertility across various studies. The application of biochar can improve soil physicochemical properties, enhance nutrient availability, and promote beneficial microbial communities. Multiple studies have demonstrated that biochar application increases soil pH, total organic carbon, total nitrogen, available phosphorus, and cation exchange capacity (Palansooriya *et al.*, 2024). For example, one study found that biochar application at 7.5 t ha⁻¹ increased soil pH by 21%, total nitrogen by 32%, and available phosphorus by 264% compared to untreated soil. Biochar also improves soil physical properties by reducing bulk density, increasing porosity, and enhancing water retention capacity. The effects of biochar can vary depending on soil type, biochar feedstock, and application rate. While biochar generally improves soil fertility, some studies have found limited or no effects in certain conditions. For instance, biochar application to fertile soil in the Nile Valley of Egypt did not alleviate yield reduction in tomatoes under saline irrigation conditions. Additionally, the combination of biochar with other amendments like food waste or mineral fertilizers can have synergistic effects on soil properties and plant growth. Biochar shows great potential as a soil amendment for

enhancing soil health and fertility. Its ability to improve soil physicochemical properties, increase nutrient availability, and promote beneficial microbial communities makes it a promising tool for sustainable agriculture. However, the effectiveness of biochar can vary depending on specific conditions, highlighting the need for careful consideration of soil type, biochar properties, and application rates when implementing biochar-based strategies for soil improvement (Palansooriya *et al.*, 2024).

Biochar's Impact on Soil Nutrient Retention and Availability

Biochar, a carbon-rich material produced from organic matter through pyrolysis, has shown significant potential for enhancing soil fertility and promoting sustainable agriculture. Its application can improve various soil properties, including physicochemical characteristics such as bulk density, cation exchange capacity, specific surface area, and porosity. Biochar also contributes to soil carbon sequestration, increased water holding capacity, and enhanced nutrient retention. While many studies report positive effects of biochar on soil properties, some have found conflicting results. The efficacy of biochar appears to depend on factors such as soil type, biochar properties, and application rates. For instance, in fertile soils under saline irrigation conditions, biochar application may not effectively mitigate crop yield reductions. Additionally, biochar can have negative impacts, including the presence of PAHs and excessive amounts of certain nutrients. In conclusion, biochar shows promise as a sustainable

soil amendment, particularly for poor or degraded soils. Its benefits include improved soil fertility, increased crop yields, and enhanced carbon sequestration. However, further research is needed to optimize biochar modification techniques and determine the long-term effects on soil fertility and plant growth under various environmental conditions (Koné and Galiegue, 2023).

Biochar as a sustainable solution for improving soil health and fertility

Biochar has emerged as a promising soil amendment for improving soil health and fertility, offering multiple benefits for sustainable agriculture. Studies have shown that biochar application can enhance soil physicochemical properties, including reduced bulk density, increased porosity, improved water retention, and increased cation exchange capacity (. These improvements in soil structure and function contribute to better nutrient availability and overall soil fertility. Interestingly, the effects of biochar on soil properties and crop yields can vary depending on the application rate, biochar type, and soil conditions. Combining biochar (2-4 t ha⁻¹) with mineral fertilizers significantly increased potato yield and water use efficiency in a loamy sand-textured Fluvisol. In contrast, (found that biochar application in over-fertilized vegetable fields had no significant effect on nitrogen use efficiency or soil fertility index, despite reducing N₂O and NO emissions. In conclusion, biochar shows great potential as a sustainable solution for improving soil health and fertility. Its ability to enhance soil organic

carbon, increase nutrient availability, and improve soil physical properties makes it a valuable tool for agricultural management (Idapuganti *et al.*, 2023).

The effect of biochar application in agricultural systems

Biochar application has shown significant potential for improving soil health and fertility in agricultural systems. Multiple studies have demonstrated its positive effects on various soil properties and crop performance. Biochar amendments have been found to increase soil pH, organic carbon content, and cation exchange capacity (CEC). These improvements in soil chemical properties can lead to enhanced nutrient availability and retention, ultimately benefiting crop growth and yield. Interestingly, the effects of biochar on soil properties and crop performance can vary depending on factors such as biochar type, application rate, and soil characteristics. Biochar's benefits were more pronounced in sandy soils compared to clay soils, with significant improvements in microbial biomass carbon, soil respiration, and plant biomass yield. Additionally, the pyrolysis temperature used to produce biochar can influence its effectiveness, as demonstrated in where higher pyrolysis temperatures resulted in greater sorption of herbicides and improved soil fertility. In conclusion, biochar application shows promise as a sustainable soil amendment for improving soil health and fertility in agricultural systems. However, it is important to note that the effectiveness of biochar can be context-dependent, and factors such as soil type, biochar

properties, and application rates should be carefully considered. Further research, particularly long-term field studies, is needed to fully understand the impacts of biochar on different soil types and cropping systems, as well as to optimize its use for sustainable agriculture (An *et al.*, 2023).

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Effect of Climate Change on Insect-Pest Dynamics

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Climate change

Climate change is the term used to describe a gradual increase in the average temperature of the Earth's atmosphere and its oceans, a change that is believed to be changing the Earth's climate forever. Global temperature has been steadily rising since 1900 with an increase of about 1°C since then. The greatest increase has been in northwestern North America, but India's temperature has increased between 0.2°C and 1°C. Moreover, the rate of global warming is increasing; temperature increased twice as fast during the last 50 years as it did in the last 100 years. The mean temperature in India is projected to increase up to 1.7°C in *kharif* (July to October) and up to 3.2° C during *rabi* (November to March) season, while the mean rainfall is expected to increase by 10 percent by 2070 (Gupta, 2011).

Impacts of climate change on insect pests

Insects are cold-blooded organisms, the temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is probably the single most important environmental factor influencing insect behaviour, distribution, development, survival and reproduction. Anthropogenic CO₂ is almost twice more important for temperature increase than other long-lived greenhouse gases combined. Although increased CO₂ should not directly deleteriously

affect insects, the temperature increases driven by the increase in anthropogenic CO₂ already affect insects in profound ways including their distribution, nutrition, phenology and role as disease vectors.

Effects of elevated CO₂ on insect pests

In general, host plants grown under elevated CO₂ are less nutritious to insect herbivores, which can affect their behaviour and performance. Phenotypic host-plant changes typically make leaf material eaten by insects less nutritious. As a consequence, insects have a more difficult time converting the food they eat into biomass. In order to mitigate the effects of less nutritious food, insect herbivores often consume more. Insect herbivore performance is positively correlated with leaf nitrogen concentrations. Zvereva and Kozlov (2010) reported that the leaf nitrogen content decreased for mustard and collard grown under elevated CO₂. Leaf chewing insect herbivore performance is positively correlated with leaf water content. Decrease in leaf water contents was observed under elevated CO₂ for both mustard and collard.

Plants can also defend themselves mechanically, either by having tough leaves or by structures such as leaf trichomes. Levels of mechanical defense are negatively correlated with herbivore performance. Elevated CO₂ increased trichome densities on radish.

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Several studies, mostly considering leaf toughness, leaf thickness, and specific leaf weight, have also observed increases in mechanical defense due to elevated CO₂. Hamilton *et al.* (2005) reported higher percent leaf damage or consumption due to cabbage white butterfly fed either mustard or collard grown under elevated CO₂. Similar results have been obtained in leaf miners on a variety of woody species. Zvereva and Kozlov (2010) detected a significant negative effect of elevated CO₂ on insect herbivore performance. They observed that overall herbivore communities were lower on plants grown under elevated CO₂ vs. ambient CO₂. This is likely in part due to higher mortality rates due to both parasitoids and other natural enemies. Natural enemies are thought to have better success under elevated CO₂ because their prey are more apparent. Insects typically take longer to develop, making them more apparent in time to natural enemies. Higher consumption rates also cause increased leaf damage and increased frass production, both cues to natural enemies. Hamilton *et al.* (2005) measured levels of herbivory in soybean grown in ambient air and air enriched with CO₂ or O₃ using free air gas concentration enrichment (FACE). Under open-air conditions and exposure to the full insect community, elevated CO₂ increased the susceptibility of soybeans to herbivory early in the season, whereas exposure to elevated O₃ seemed to have no effect. In the region of the canopy exposed to high levels of herbivory, the percentage of leaf area removed increased from 5 to more than 11% at elevated CO₂.

They found no evidence for compensatory feeding at elevated CO₂ where leaf nitrogen content and C:N ratio were unaltered in plants experiencing increased herbivory. However, levels of leaf sugars were increased by 31% at elevated CO₂ and coincided with a significant increase in the density of the invasive species *Popillia japonica* (Japanese beetle). In two-choice feeding trials, Japanese beetles and Mexican bean beetles (*Epilachna varivestis*) preferred foliage grown at elevated CO₂ to foliage grown at ambient CO₂. Hence, the increased level of sugar in leaves grown at elevated CO₂ may act as a phagostimulant for the Japanese beetle.

Effects of elevated temperature on insect pests

Many of the effects of increased temperature on insect performance have to do with the direct effects of temperature on insects. Because insects are exothermic, they tend to be more active under warmer conditions. A typical effect of elevated temperature is therefore to increase consumption rates and therefore decrease the time to pupation, making them less apparent to natural enemies and in some cases increasing the potential number of generations per season. It has been estimated that with a 2°C temperature increase insects might experience one to five additional life cycles per season (Yamamura and Kiritani, 1998). Elevated temperatures increase gypsy moth performance, both decreasing its development time and increasing its survival rate (Williams *et al.*, 2003). However the survival rate of another member of its genus, the nun moth, is very different under increased temperatures.

If gypsy moths react more favorably to future environments than competitors, they may become more prone to outbreak. Elevated temperatures (on the scale of expected global warming) can also have direct effects on plant phenotypes, but not typically to the extent that elevated CO₂ has, and those factors affected (like total nonstructural carbohydrates, starches, and sugars) don't typically affect insect herbivores as much as host-plant characteristics affected by elevated CO₂. Temperature may change gender ratios of some pest species such as thrips (Lewis, 1997) potentially affecting reproduction rates. Insects that spend important parts of their life histories in the soil may be more gradually affected by temperature changes than those that are above ground simply because soil provides an insulating medium that will tend to buffer temperature changes more than the air (Bale *et al.*, 2002). Lower winter mortality of insects due to warmer winter temperatures could be important in increasing insect populations (Harrington *et al.*, 2001). Insect species diversity per area tends to decrease with higher latitude and altitude (Andrew and Hughes, 2005), meaning that rising temperatures could result in more insect species attacking more hosts in temperate climates (Bale *et al.*, 2002).

Effect of changes in rainfall pattern on insect pests

Early and timely planting become more uncertain under climate change. During the 2009 rainy season, delay in onset of monsoons by 45 days resulted in delayed plantings of pigeonpea that are

prone to damage by *Helicoverpa armigera* and caused heavy damage (Sharma, 2010). As with temperature, precipitation changes can impact insect pest predators, parasites, and diseases resulting in a complex dynamic. Fungal pathogens of insects are favored by high humidity and their incidence would be increased by climate changes that lengthen periods of high humidity and reduced by those that result in drier conditions. Some insects are sensitive to precipitation and are killed or removed from crops by heavy rains, this consideration is important when choosing management options for onion thrips (Reiners and Petzoldt, 2005).

Conclusion

Species life history (evolutionary) adaptations may obscure our ability to detect species response to climate change - accordingly, species respond differently to changes in thermal environments. There are many interactions and it is extremely difficult to predict the impact of climate change on insect pests in the future, but we may expect an increase of certain primary pests as well as secondary pests and invasive species. The best economic strategy for farmers to follow is to use integrated pest management practices to closely monitor insect and disease occurrence. Keeping pest and crop management records over time will allow farmers to evaluate the economics and environmental impact of pest control and determine the feasibility of using certain pest management strategies or growing particular crops. Some of the potential adaptation strategies could be developing

IPM with more emphasis on biological control and changes in cultural practices, pest forecasting using recent techniques such as simulation modeling and alternate production techniques.



Mating Disruption Technology for Management of Insect-Pests

Mukesh Netwal

Introduction

Insect pheromones are important chemical compounds, single or blend of compounds, usually released by one sex of species to elicit behavioural response in the opposite sex for mating. In most of the studied species, pheromones are released by female individuals but there are exceptions to this where male individuals release the pheromone to attract females.

Based on the behaviour induced in receiving individuals these pheromones can be classified as sex pheromones, aggregation pheromones and alarm pheromones.

- ✓ Sex pheromones are released usually by females to attract the males for mating and are said to be most potent stimuli for sensory reception and eliciting behaviour in receiving individual.
- ✓ An aggregation pheromone is released by either sex of the species and attract both sexes of same species for locating food source and mate finding.
- ✓ Alarm pheromones are released when there is threat to the community to communicate possible threat and to initiate dispersion behaviour in individuals of community.

For several decades researchers have tried to exploit these insect behaviour modulating chemicals to develop eco-friendly pest management practices.

Sex pheromones are mostly studied in lepidopteran insects and being exploited for monitoring of pest and also in some cases for mass trapping. The aggregation pheromones are effectively used for mass trapping as it attracts both sexes and they are mostly studied and reported in coleopteran pests. Apart from monitoring and mass trapping, mating disruption is one concept where synthetic pheromone compounds are employed to achieve mating failure of insect pests in given area or crop to reduce pest pressure and hence pesticide load on the crop.

Mating disruption: the concept and mechanisms

If the air in the crop canopy, be it a seasonal crop or orchard, is saturated with synthetic sex pheromone then male individuals of the species would not be able to locate the females as synthetic pheromone releasing from different point source will disorient the males towards high dose artificial pheromone source than low dose female released pheromones. It leads to unsuccessful attempt of males to locate the females and hence failure in mating and further population built-up. Although the concept behind mating disruption seems to be very simple but it needs thorough knowledge of the physiological and behavioural aspects of insect pest to develop effective mating disruption strategy which would be able to compete with insecticide based management strategies. It is also important to

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note that besides physiology and behaviour, it also involves physics, chemistry, materials science, atmospheric science, biochemistry, and sometimes biogeography (Carde, 2007). The prevailing environmental conditions in a given crop area and in particular season can also affect the efficacy of mating disruption.

Miller and Gut (2015) reviewed the different mechanisms for principle cause of mating disruption proposed by earlier workers and proposed that there two main mechanisms under which it can be classified based on whether at the beginning of sexual activity the disruptant has or has not impaired the physiology of either male or female or chemical nature of female plume. When there is no such impairment the phenomenon is called competitive disruption which further classified as competitive attraction, induced allopatry and induced arrestant. On the other hand when impairment happens then it is classified as non-competitive disruption. Non-competitive disruption can be due to suppression of female calling behaviour and mating or impairment of signal spatial integrity (masking/camouflage) or impairment in signal reception due to variation or adulteration of signal quality. Adaptation or habituation of male peripheral sensilla due to prolonged exposure to pheromone plume and exposure at high pheromone doses leads to desensitisation of nerves which ultimately results in no response of males to any pheromone lure in the environment and hence no attraction and mating.

Physiology of mating disruption

For the successful population growth of insect, mating and oviposition must takes place at correct physiological maturity which plays crucial role and it is known that physiology of both males and females changes over time and the timing of first reproduction is decisive for population growth of insects (Carey, 1993). The physiological mechanism behind mating disruption is unknown but many theories have been suggested. Mating disruption is achieved due to the delayed mating as older females shows reduced fecundity. Oosorption is another phenomenon wherein changes in physiology and resource allocation result in production of unfertilized oocytes which are resorbed before oviposition. The unfertilisation in this case may happen due to lack of mates as a result of high dose of synthetic pheromones.

Haung and Subramanyam (2003) studied the effect of delayed mating in a storage insect pest, *Plodia interpunctella* by delaying the mating of virgin male or female by a day and results revealed that fecundity decreased to 25 eggs as compared to 161 eggs in normal conditions. Egg viability decreased by 22%/d only when females were delayed from mating. Males delayed from mating for 5 d were unable to inseminate females. Reduced egg fertility in females that experience a mating delay can be caused by degenerative oocytes which prevent the successful transfer of a spermatophore to the bursa copulatrix. Reduced attractiveness of females by aging decreases mating opportunities and results in reduced fertility and fecundity.

Pest management through mating disruption

According to Miller and Gut (2015) mating disruption products have been developed for more than 20 important insect species and are used on more than 7,50,000 hectares worldwide. Pink bollworm, *Pectinophora gossypiella* was among the first insect species for which this strategy was commercialised. It is a key pest of cotton which has become threat to cotton cultivation India. Patil (2007) demonstrated the use of mating disruption of this pest using PB Rope L at Dharwad, Karnataka. Pheromone dispensing point source @ 200 ha⁻¹ showed promising results. The efficacy can be ascertained from observations made on very low math catches in treated plots, about 70 per cent reduction in boll damage, 52-56 per cent reduction in larval population and 32-40 per cent higher cotton yield. Although in recent past mating disruption is being evaluated for several pests in India but there are some constraints which must be taken care of to enhance the effectiveness of this tool.

Constraints

Carde (1995) has documented some of the important constraints faced for commercialisation and use of mating disruption technique in field. Stringent demands for data on toxicology and environmental fate of mating disruption product is one of the important hurdle in many countries. Convincing registration agencies and growers about cost effectiveness is another main hurdle. The type of formulation will have its major impact on mating disruption success which is not the case with insect-

icides. Male insect response to pheromone compound, chemical characteristics of pheromone, physical environment and economic considerations also influence the success of mating disruption (Gut *et al.*, 2004).

The person engaged in pest management through mating disruption should have knowledge about biology of insect pests, effect of environmental factors on insect pest dynamics, crop phenology and its relation with insect pest population built-up etc. Proper monitoring of pest is one of the important factor as mating disruption products need to be applied before pest could start reproduction in crop area. Mating disruption product is mostly used against one major pest in a given crop but minor pests remain unattended so it is important that grower has knowledge about other associated pests and management tactics for them which may include use of insecticides. While using mating disruption product in field the uniform distribution of pheromone dispensers or point source is crucial to maintain uniform saturation of pheromone plume in whole field or cropped area. The treatment must start early in the season so as to avoid initial mating and subsequent egg laying by pest.

Conclusion

Considering the rising concern of pesticide residue in food, water and environment and demand of consumers for safe food, it is necessary to opt for better eco-friendly and economically effective pest management strategies. Mating disruption using insect pheromones can be one important tool in inte-

grated pest management to achieve the sustainable pest management with food security and safety. Much efforts still need to be done in India to encourage this technology at policy level and also at farm level.



Evaluation of Cereal Protein Quality for Poultry

Neelam Kumari and Sudarshan Mahala

Introduction

Cereals and cereal by-products are widely used to feed pigs and poultry. It provides carbohydrates in the form of starch, NSP and provide significant amount of protein when fed to animals. Normal protein content of cereals varies from 7-16% depending on various factors. Poultry diets generally constituted 50-70 % of cereals and cereal by products contributing 6-12% of the final diet's crude protein (CP) content. However, the nutritional quality of protein in dietary ingredients for poultry depends on their amino acid composition and bioavailability. Out of the 22 amino acids ten amino acids cannot be synthesised in large quantities and need to be supplied through the diet. They are called essential amino acids (EAA) or indispensable amino acids. Cereal protein quality mainly depends on concentration of these essential amino acids. If a cereal protein supplies all these EAA in adequate quantities it can be said that cereal protein of high quality. However, many of the cereal protein/vegetable proteins lack one or more essential amino acids compared to animal source protein (ASP) making them inferior to ASP.

How to test the cereal protein quality

Protein quality evaluation mainly relies on

extent to which amino acids are digested and absorbed from the ingredients. This is achieved by feeding the protein source to the bird and estimating the digestibility and retention of protein of that particular ingredient (in-vivo estimation), estimating the plasma amino acid concentration, or subjecting the ingredient to chemical methods and also by providing the same environment as in GIT of bird (*In-vitro* estimation).

In-vivo analysis

Involves experimentation with live birds. Various types of in vivo experiments to decide the protein quality are

Growth assays/weight gain methods

Direct bioassay to determine the quality of cereal protein by feeding to birds and recording the growth/weight gain.

Gross protein value (GPV): The extra live weight gain per unit of supplementary test protein stated as a proportion of the extra live weight gain per unit of supplementary casein supplied. Test cereal protein is fed to group of birds and compared with that of weight gain in birds that were fed with pure protein source casein.

Protein efficiency ratio (PER): Oldest method of protein quality assessment. Here the growth response

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of bird to dietary protein is expressed as weight gain to unit of protein in the diet.

Net protein retention (NPR): It is the method in which growth rate of birds that were fed with test protein is compared with another groups of birds that were not provided any protein in the diet. It gives the proportion of protein used for maintenance and also protein used for weight gain.

Nitrogen balance methods

Digestibility assay: The assay of digestibility has become the most favoured technique for measuring protein available to bird. Digestibility assays may be divided into excreta and ileal digestibilities. Excreta digestibility involves the collection of excreta from intact, caecectomised or colostomised birds, depending on the purpose of each technique. In this method protein retention of bird from a given feed is estimated by analysing protein in feed and faeces (excreta digestibility) or by collecting the digesta in the ileum of bird.

Biological value (BV): This is the direct measure of the proportion of the food protein that can be utilized by the animal for synthesizing body tissues and compounds. BV is defined as the proportion of the absorbed nitrogen that is retained by the body

Net protein utilization (NPU): This involves slaughter studies to estimate the proportion of protein that was deposited in body tissue. The difference between the nitrogen content of birds fed with test protein and birds fed with N free diet will be compared as a ration of N intake.

Protein replacement value (PRV): The N retention

percentage of birds fed with test protein is compared with that of standard protein as a proportion of N intake in the diet. This assay considers the protein deposition rather than digestibility of protein in the diet.

Disadvantage of *in-vivo* assays

In-vivo methods of estimation are time consuming, costly and needs much labour and data processing. Not suitable to conduct these assays in a commercial setting.

Indirect *in-vivo* methods

Plasma amino acid assays: The level of free amino acids in blood can reflect the availability in the dietary protein. In this method, constant plasma free amino acid concentrations during starvation are used as a reference and compared with concentrations of post-prandial limiting amino acids. However the amino acid concentration depends on nutritional status of bird. When the bird is in positive N balance it reflect the absorbed AA but in negative N balance AA of catabolized protein are reflected in plasma AA concentration.

In-vitro methods

Quality of cereal protein can be evaluated using less expensive and time consuming chemical methods, termed *in-vitro* methods. In commercial poultry production systems *in-vitro* digestibility assays are considered as alternative to *in-vivo* experimentation for characterizing protein quality of ingredients used in ration formulation. This method of testing is a chemical method which is less time consuming, less expensive, reproducible, cheaper

than available in vivo assays and simple to perform while giving fast results. Different steps in quality estimation mimics the bird digestive tract. Pepsin digestibility test is the frequent and method of choice for quick evaluation of protein sample during quality control and in most research settings. Different *in-vitro* methods are (Bryan and Classen, 2020)

Chemical methods

Kjeldhal method: Estimation of nitrogen content of ingredient which is directly proportional to protein content by using acid digestion followed by distillation and titration

Amino acid analysis: In this method the concentration of each amino acid in the ingredient is estimated by using chromatographic techniques TLC/ UTLC/HPLC (Ravindran and Bryden, 1999)

Solubility index method: Not a routine method. Protein with more solubility indicates more digestibility and bioavailability of amino acids to bird.

Protein dispensability index: Involves high speed mixing of a protein sample in water, followed by the assessment of solubility. To estimate the quality of animal protein taking into consideration the nitrogen fraction that are precipitated by copper and phosphor tungstic acids refractory to pepsin digestibility and soluble in hot water.

pH drop method: Hydrolysis of protein in the gut releases H^+ which reduces the pH of reaction media. The rates of hydrolysis of the protein samples were evaluated as an indirect measure of the pH of the reaction mixture over time.

Closed enzymatic method: These systems are used

to evaluate the digestibility of nutrients either with a single enzyme (usually pepsin) or a mixture of gastric, pancreatic, and intestinal enzymes, simulating part or all the *in vivo* digestive process. The pepsin assay is widely accepted by the feed industry because it is relatively simple, inexpensive, and rapid, and many samples can be compared at the same time. This system is most suitable to evaluate the quality of cereal protein. Ex; Pepsin assay, pancreatin assay, multi enzyme assay

Microbiological assays: Microbiological assays employing *Streptococcus faecalis*, *Streptococcus aureus*, *Lactobacillus arabinosus*, *Streptococcus zymogenes*, *Tetrahymena pyriformis*. This method estimates the microbial growth as the response criterion to assess the quality of proteins or bioavailability of amino acids.

Disadvantage of in-vitro assays: Do not give a true replication of normal *in vivo* digestive conditions.

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Nutritional Factor Affecting Lean Tissue Growth

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Introduction

Lean tissue growth is associated with improvement in rate and efficiency of live weight gain and reduced lipogenesis and carcass fatness. The basic principle determining the response of lean tissue growth to change in nutrient intake is qualitatively similar for many animals and poultry species. Ruminants have inherent lower appetite; they probably never consume sufficient energy to express their full genetic potential of lean growth. While appetite of growing pigs may exceed their inherent capacity for lean tissue growth and energy intake must be restricted to prevent excessive fat development. Within species, lean tissue growth capacity depends on: live weight, sex, breed and genotype (Campbell, 1988). There are various nutritional factors which influence the lean tissue growth, which includes: protein and energy intake; feed intake, digestibility and biological value; energy intake and protein deposition; live weight, sex and genotype; exogenous growth hormone administration and transgenic animals. (Campbell, 1988).

What is lean meat?

Lean meats are meats with a relatively low-fat content. Skinless chicken and turkey and red meat, such as pork chops, with the fat trimmed off

are examples of lean meat. Lean meat is a good source of protein with a lower fat content and therefore lower calorie content. The fat on a pork chop accounts for about two thirds of its fat content and the skin on chicken can account for 80 per cent of its fat content.

Lean meat composition (%)

- ✓ CP- 15.0
- ✓ Fat- 22.0
- ✓ Water- 60.0
- ✓ Minerals- 3.0

Health benefits of lean meat

Lean meats are a good source of protein and have fewer calories than non-lean meats. Lean meats are popular amongst people following low calorie and low-fat diets. Poultry is a good source of selenium, vitamins B₃ and B₆, and choline. Selenium has antioxidant properties which help to prevent free radicals from damaging cells. Selenium also helps the immune system. Vitamins B₃ and B₆ help the body to convert carbohydrate into glucose. Choline helps with nerve function and can reduce inflammation.

Nutritional factors that influence the lean tissue growth

Relation between protein and energy intake:

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Protein deposition can be inhibited by an inadequate intake of either protein or energy or both. Independent effects of protein and energy intake on protein deposition were first reported in the 1950s by Blaxter and Wood (1952) for milk-fed calves.

Effect of sex: There is difference in growth performance and body composition between entire male and female animals and between these two sexes and castrated males of the same breed and genotype (Searle and Griffiths, 1976).

Effect of genotype: The same weight, genotypes which are heavier at maturity generally grow faster and contain less fat in their empty bodies and carcasses than do animals of smaller mature size. Animals of higher genetic potential for lean tissue growth are, however, more sensitive to nutritional stress than those of lower lean tissue growth potential. Animals with higher lean tissue growth capacities require more dietary protein (amino acids) and at the same level of energy intake will exhibit more rapid and leaner growth than those of lower lean tissue growth potential. Animals with higher lean tissue growth potential can also be given higher levels of energy intake without exhibiting the same deterioration in growth performance and increased carcass fatness as those of lower lean tissue growth potential (Campbell, 1988).

Effects of live weight: Animals of the same species, sex and genotype the slope of the linear component of the relationship between energy intake and protein deposition is largely unaffected by live weight. As the animal progresses towards maturity, its capacity

for protein deposition, even at levels of energy intake below which maximal protein deposition occurs, becomes increasingly constrained by intrinsic rather than nutritional factors.

Exogenous growth hormone administration:

Using exogenous GH administration in sheep, cattle and pigs indicate that the endocrine system, and endogenous GH secretion in particular, is a major factor inhibiting lean tissue growth in these species. The effects of exogenous porcine GH (pGH) administration increased protein deposition at equivalent levels of energy intake and reduced fat deposition, resulting in a marked reduction in the fat: protein ratio of energy gain and in body fat content.

Transgenic animals: The most exciting developments in our attempts to manipulate animal performance have been the alteration of genetic merit by direct gene transfer. A number of transgenic animals have exhibited elevated pGH levels and superior growth performance compared to their control litter-mates.

Conclusion

Nutrient availability can act as a major factor to expression of lean tissue growth potential in farm animals. The dietary requirement of growing animals are determined by the capacity of protein growth, which in turn is determined by factors such as live weight, sex and genotype. Lean tissue growth is controlled by the various animal factors and by the nutritional and climatic environments.

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Feeding Management in Animals

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Introduction

Feeding management in animals involves providing the right type and amount of feed to meet their nutritional needs, ensuring optimal health and productivity. This includes balancing roughage and concentrate feeds, adjusting rations based on the animal's age, stage of production (e.g., lactating, growing, dry) and environmental conditions and monitoring their health and well-being.

Key aspects of feeding management:

Ration Balancing

Rations should be carefully balanced to provide sufficient energy, protein, vitamins and minerals.

Roughage: Provides fiber and energy. Examples include hay, pasture and straw.

Concentrates: Provide energy and protein. Examples include grains, seeds and feed supplements.

Mineral and Vitamin Supplements: Ensures adequate intake of essential micronutrients. Animals should have access to adequate minerals, often provided through lick blocks or mineral mixtures.

Water: Essential for digestion and overall health. Clean, fresh water must always be readily available.

Adjusting Rations

Rations should be adjusted based on the ani-

mal's needs and production level.

Age and Stage of Production: Young animals, pregnant animals and those in high production need specific nutritional requirements.

Environmental Factors: Extreme heat or cold can affect feed requirements.

Individual Needs: Animals with different production goals (e.g., milk, meat, wool) need tailored rations.

Feed Quality and Safety

Properly storing and processing high-quality feedstuffs is crucial.

Choose high-quality feed ingredients: Ensure proper storage and handling to prevent spoilage and contamination.

Regularly analyze feed: To determine nutrient content and ensure it meets the animal's needs.

Avoid overfeeding or underfeeding: Both can lead to health problems and reduced productivity.

Feeding Practices

Offer feed in several small meals: Especially during hot weather or for high-yielding animals. Feeding in several small meals, especially for high-yielding animals, can improve digestion and reduce the risk of digestive problems.

Provide access to feed for extended periods: All-

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ow animals to graze or eat at their own pace. Proper grazing practices, such as rotational grazing, can help maintain pasture health and provide adequate forage for animals.

Maintain clean feeding areas: Prevent contamination and disease.

Monitoring and Adjustments

Regularly monitoring animal health and performance, as well as feed quality and palatability, allows for necessary adjustments to the feeding plan.

Observe animal health and body condition: Look for signs of malnutrition or overfeeding.

Adjust rations as needed: Based on the animal's response and environmental conditions.

Consider using non-conventional feeds: To reduce competition with humans and improve feed efficiency.

Dairy Cattle: High-yielding dairy cows may benefit from being fed three times a day, with frequent concentrate feeding to support normal rumen motility and milk fat levels. Lactating animals require a higher intake of protein and minerals to support milk production.

Growing Animals: Calves below one year should receive sufficient concentrates in addition to roughage to ensure optimal growth.

Dry Cows: Dry cows should have a balanced diet to prepare them for the next lactation, and mineral requirements should be increased before and after parturition.

Sheep and Goats: Feeding management for sheep and goats is similar to cattle, with considerations for

their grazing behaviour and specific nutritional needs during lambing and kidding.

Biofertilizers and Mycorrhiza: The Living Partners in Soil Nutrient Cycling

K. C. Singh, Greena P. G., M. S. Yashaswini, Naresh Jayavelu and Ayesha Siddiqua

Abstract

Biofertilizers and mycorrhizae are vital components of sustainable agriculture, playing a crucial role in soil nutrient cycling and enhancing plant productivity. These living organisms work in synergy with plant roots, promoting nutrient uptake, improving soil structure, and reducing the dependence on chemical fertilizers. Biofertilizers, including nitrogen-fixers and phosphate-solubilizing microbes, contribute to nutrient availability through biological processes. Mycorrhizal fungi, especially arbuscular mycorrhizae, form symbiotic associations with plant roots, extending the root's access to nutrients like phosphorus and enhancing water absorption. Together, they increase crop yield, support soil biodiversity, and improve resilience against environmental stress. Integrating these biological partners into farming systems not only boosts efficiency but also ensures long-term ecological balance. This article explores their types, mechanisms, benefits, application techniques, and future potential, highlighting their role as sustainable alternatives in modern agriculture. Emphasis is also given to their synergistic interactions and the challenges faced in mainstream adoption.

Introduction

In the pursuit of sustainable agriculture and environmental conservation, the importance of soil health has moved to the forefront of global scientific discourse. Among the various components that contribute to fertile, productive soils, microbial communities especially biofertilizers and mycorrh-

izae play a critical and often underappreciated role. These living organisms are not merely passive residents in the soil; they are active participants in nutrient cycling, plant growth promotion, and ecosystem stability. The integration of these natural allies into agricultural systems not only reduces the dependence on chemical fertilizers but also enhances

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soil structure, microbial biodiversity, and crop resilience.

Understanding Soil Nutrient Cycling

Soil nutrient cycling refers to the continuous movement and transformation of essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), and micronutrients within the soil-plant system. This cycle is driven by complex interactions among soil organisms, organic matter, and plant roots. Traditionally, chemical fertilizers have been used to replenish nutrients extracted by crops. However, overreliance on synthetic inputs disrupts natural nutrient cycles, leading to environmental issues such as leaching, soil acidification, and microbial imbalance. Biofertilizers and mycorrhiza offer a biological approach to enhancing soil nutrient cycling by working synergistically with plant systems.

What are Biofertilizers?

Biofertilizers are formulations containing live or latent microbial strains that colonize the rhizosphere or the interior of the plant and promote growth by increasing the availability or uptake of primary nutrients. Unlike chemical fertilizers, biofertilizers are eco-friendly, cost-effective, and sustainable.

Types of Biofertilizers

Nitrogen-fixing biofertilizers: *Rhizobium*, *Azotobacter*, *Azospirillum*

Phosphate-solubilizing microorganisms (PSM): *Bacillus*, *Pseudomonas*, *Aspergillus*

Potassium-solubilizing bacteria (KSB): *Bacillus*

mucilaginosus, *Frateruia aurantia*

Zinc-solubilizing bacteria: *Gluconacetobacter*, *Burkholderia*

Silicate solubilizing bacteria

Plant growth-promoting rhizobacteria (PGPR):

multi-functional microbes that enhance growth through various mechanisms. These biofertilizers directly or indirectly influence soil nutrient cycles by fixing atmospheric nitrogen, solubilizing minerals, producing growth hormones, and stimulating root development.

What is Mycorrhiza?

Mycorrhiza refers to the mutualistic association between certain soil fungi and plant roots. This relationship enhances the plant's ability to absorb nutrients, particularly phosphorus, from the soil. In exchange, the fungi receive carbohydrates and other organic compounds from the plant.

Types of Mycorrhizae

Arbuscular Mycorrhizal Fungi (AMF): The most common, forming arbuscules inside the root cortex.

Ectomycorrhizae: Form sheaths around the roots, common in forest trees.

Ericoid and Orchid Mycorrhizae: Specific to ericaceous plants and orchids.

AMF are particularly significant in agriculture due to their compatibility with a broad range of crops and their efficiency in phosphorus uptake.

Mechanisms of Nutrient Cycling by Biofertilizers

Nitrogen Fixation: Biological nitrogen fixation (BNF) is the conversion of atmospheric N₂ into ammonia by diazotrophic bacteria. Symbiotic fixers

like *Rhizobium* form nodules on legume roots, while free-living bacteria like *Azotobacter* fix nitrogen in the soil independently.

Phosphorus Solubilization and Mineralization:

Most soil phosphorus is insoluble and unavailable to plants. PSMs secrete organic acids such as gluconic acid and citric acid, which chelate calcium and iron, releasing phosphate ions. Mineralizing microbes decompose organic phosphorus compounds, enhancing availability.

Potassium and Micronutrient Mobilization:

Certain microbes release acids and enzymes that convert fixed forms of potassium and trace elements like zinc and iron into plant-available forms.

Siderophore Production: Some biofertilizers produce siderophores molecules that bind iron and make it more accessible to plants. This also inhibits pathogens by depriving them of iron.

Phytohormone Production: Indole-3-acetic acid (IAA), gibberellins, and cytokinins produced by PGPR enhance root elongation and branching, increasing the root surface area for nutrient absorption.

Mycorrhizal Contributions to Nutrient Cycling

Enhanced Phosphorus Uptake: AMF hyphae extend beyond the root depletion zone, accessing phosphorus that is otherwise out of reach. They store phosphorus in vesicles and transfer it to the host plant.

Improved Nitrogen Use Efficiency: Though not nitrogen-fixers, mycorrhizae enhance nitrogen uptake by increasing root surface area and facilitating

ammonium and nitrate absorption.

Soil Aggregation and Structure: Mycorrhizal hyphae secrete glomalin, a glycoprotein that stabilizes soil aggregates and enhances porosity, promoting better root penetration and water movement.

Stress Resistance and Disease Suppression:

Mycorrhizal plants are more resistant to drought, salinity, and pathogens. This is due to improved nutrition, induced systemic resistance, and competitive exclusion of harmful microbes.

Synergy between Biofertilizers and Mycorrhiza

Combining biofertilizers with mycorrhizae creates a synergistic effect on nutrient cycling and plant health. For example:

- ✓ *Rhizobium* and AMF inoculation in legumes leads to better nitrogen fixation and phosphorus uptake.
- ✓ PSBs in combination with AMF improve root colonization and phosphate solubilization.
- ✓ Co-inoculation reduces the need for chemical fertilizers by up to 50% without compromising yield.

This integrated approach enhances microbial diversity, balances nutrient availability, and sustains soil fertility over time.

Application Methods and Best Practices

To maximize the benefits of biofertilizers and mycorrhizae, certain application practices should be followed:

Seed treatment: Coating seeds with a microbial slurry before sowing.

Root dipping: Common in vegetable nurseries

before transplanting.

Soil application: Mixing with compost or carrier materials like vermiculite and applying near the root zone.

Fertigation and foliar sprays: For established crops in field conditions.

Key considerations include moisture, temperature, pH, and the absence of chemical residues that could harm microbial viability.

Case Studies and Field Evidence

Several studies and field trials have demonstrated the effectiveness of biofertilizers and mycorrhizae:

- ✓ In paddy fields, *Azospirillum* inoculation increased grain yield by 15-20% while reducing urea application.
- ✓ Chickpea plants inoculated with *Rhizobium* and AMF showed 25% more nodules and improved protein content.
- ✓ In horticulture, biofertilizer and AMF application in banana and citrus enhanced fruit quality and shelf life.

These findings reinforce the relevance of microbial partners in nutrient dynamics and productivity.

Challenges in Adoption

Despite proven benefits, widespread adoption of biofertilizers and mycorrhizae faces hurdles:

- ✓ Lack of awareness and technical knowledge among farmers.
- ✓ Quality control issues in commercial formulations.

- ✓ Short shelf-life and storage limitations
- ✓ Compatibility with existing farming practices

Addressing these challenges requires policy support, farmer training, and investment in microbial research and extension services.

Future Prospects and Innovations

The future of biofertilizer and mycorrhiza use lies in:

Next-generation bioformulations: Multi-strain consortia tailored for specific crops and soil types

Nanotechnology integration: To improve delivery, survival, and performance.

Digital agriculture: Using AI and soil sensors to optimize microbial applications.

Policy and subsidy support: To encourage the shift from chemical to biological inputs.

A concerted effort is needed to mainstream these sustainable solutions into global agricultural systems.

Conclusion

Biofertilizers and mycorrhiza are not just alternatives to chemical fertilizers; they are essential biological allies in restoring and maintaining soil health. By tapping into their natural processes, we can design farming systems that are not only productive but also environmentally responsible. As living partners in the soil, these microbes embody the principles of sustainability, efficiency and resilience. The challenge ahead is to recognize their value, understand their ecology, and integrate them seamlessly into modern agriculture.

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Nanoparticles Extraction from Fruits and Vegetables: A Greener Frontier in Nanotechnology

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Abstract

Nanotechnology is revolutionizing various sectors, from medicine and agriculture to food safety and environmental protection. One of the most promising approaches within this field is the green synthesis of nanoparticles using natural plant sources, particularly fruits and vegetables. This eco-friendly and cost-effective method avoids toxic chemicals, utilizing the phytochemicals naturally present in plant materials to reduce metal ions and stabilize nanoparticles. Fruits and vegetables such as banana, orange, tomato, pomegranate, and broccoli are rich in antioxidants, flavonoids, and polyphenols that act as reducing and capping agents. The resulting nanoparticles possess enhanced bioactivity and are used in antimicrobial, anticancer, catalytic, and environmental applications. This article explores the principles, mechanisms, methods, and applications of nanoparticle extraction from fruits and vegetables, offering insight into how waste from our kitchens can transform into valuable scientific resources. Challenges, safety concerns, and future prospects in scaling up green nanotechnology are also discussed.

Introduction

The world is witnessing a surge in the application of nanotechnology due to its potential to manipulate matter at the nanoscale (1-100 nm), resulting in materials with unique physical, chemical and biological properties. One of the recent and sustainable developments in this field is the green synthesis of nanoparticles, which utilizes biological agents especially plant extracts for nanoparticle production. Fruits and vegetables are not just dietary

essentials; they are biochemical powerhouses rich in natural antioxidants, enzymes, flavonoids, and phenolic compounds. These constituents are capable of reducing metal salts to nanoparticles and stabilizing them without the need for harmful chemicals or energy-intensive processes. This green synthesis approach is gaining popularity for being environmentally friendly, cost-effective and scalable. It also aligns with global efforts to reduce the ecological footprint of nanotechnology and to

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convert agro-waste into valuable products.

Principles of Green Synthesis

The green synthesis of nanoparticles follows the basic principle of reducing metal salts (like AgNO_3 , HAuCl_4 or ZnSO_4) into metallic nanoparticles using plant-derived phytochemicals.

Role of Plant Extracts

Plant extracts act in two critical capacities:

Reducing Agents: Flavonoids, phenols, alkaloids, terpenoids, and ascorbic acid reduce metal ions into atoms.

Capping/ Stabilizing Agents: These same biomolecules stabilize nanoparticles by preventing aggregation, leading to monodispersed and bio-compatible nanostructures.

Mechanism of Nanoparticle Formation

The green synthesis involves three main steps:

Activation Phase: Reduction of metal ions into metal atoms using plant extracts.

Nucleation Phase: Atoms coalesce to form nanoparticle nuclei.

Growth Phase: Nanoparticles grow to stable sizes, with phytochemicals acting as capping agents.

Factors such as extract concentration, pH, temperature, and metal salt concentration influence the size, shape and functionality of the nanoparticles.

Fruits and Vegetables as Nanoparticle Synthesizers

Banana (*Musa spp.*): Banana peel extract contains polyphenols, carotenoids, and flavonoids that can reduce silver and gold ions into nanoparticles. These are effective in antimicrobial applications and wound

healing.

Orange (*Citrus sinensis*): Orange peel is rich in ascorbic acid, limonene, and citric acid, which facilitate nanoparticle formation. Silver nanoparticles synthesized using orange peel show excellent antibacterial activity.

Tomato (*Solanum lycopersicum*): Tomato pulp extract, due to its lycopene and polyphenol content, is used in the synthesis of gold and silver nanoparticles. These are effective in cancer therapy and catalysis.

Pomegranate (*Punica granatum*): Rich in ellagic acid and anthocyanins, pomegranate rind extract is effective in producing stable silver and gold nanoparticles used for drug delivery and anticancer studies.

Broccoli (*Brassica oleracea*): Contains sulforaphane, glucosinolates, and other antioxidants, making it ideal for zinc and selenium nanoparticle synthesis. These have applications in detoxification and oxidative stress reduction.

Extraction and Synthesis Process

The general procedure for synthesizing nanoparticles using fruit and vegetable extracts includes:

Preparation of Plant Extract

- ✓ Wash and chop fresh or dried plant material.
- ✓ Boil in distilled water or ethanol to extract bioactive compounds.
- ✓ Filter the extract for use in synthesis.

Mixing with Metal Salt Solution

- ✓ Add extract dropwise into a metal salt solution.

- ✓ Maintain constant stirring at ambient or slightly elevated temperatures.

Observation of Color Change

A color shift (e.g., from yellow to brown or purple) indicates the formation of nanoparticles.

Characterization Techniques

UV-Vis Spectroscopy: Confirms nanoparticle formation.

XRD (X-ray Diffraction): Determines crystalline nature.

FTIR (Fourier-Transform Infrared Spectroscopy): Identifies functional groups.

SEM/TEM (Electron Microscopy): Analyzes shape and size.

Zeta Potential: Evaluates stability.

Applications of Biosynthesized Nanoparticles

Antimicrobial Activity: Nanoparticles disrupt microbial cell membranes and interfere with replication, showing potent action against bacteria and fungi. Silver nanoparticles from orange or banana peel have shown inhibition against *E. coli*, *S. aureus*, and *Candida albicans*.

Cancer Treatment: Gold nanoparticles from tomato extract have been studied for targeted drug delivery, photothermal therapy, and imaging in cancer treatment.

Catalysis: Fruit-extract-based nanoparticles serve as green catalysts in reactions such as dye degradation, reduction of nitrophenols and hydrogenation reactions.

Environmental Cleanup: Zinc and iron nanoparticles remove heavy metals from wastewater and

act as adsorbents for environmental pollutants.

Food Packaging: Incorporating these nanoparticles into biodegradable films enhances shelf life by providing antimicrobial properties.

Advantages of Fruit and Vegetable-Based Nanoparticles

Eco-friendly: No toxic chemicals or residues.

Cost-effective: Utilizes kitchen/agro-waste.

Scalable: Suitable for industrial-scale synthesis.

Biocompatible: Safer for medical applications.

Energy-efficient: Requires ambient conditions.

Challenges and Limitations

Variability in Composition: Seasonal and regional variation in plant phytochemicals can affect reproducibility.

Standardization: Lack of universal protocols for synthesis and characterization.

Scalability Issues: Transition from lab to industrial scale needs optimization.

Toxicological Data: Long-term biosafety of nanoparticles requires further studies.

Regulatory Hurdles: Approval for clinical or commercial use is complex and time-consuming.

Future Perspectives

Integration with AI: Predictive models for optimizing synthesis parameters.

Biowaste Valorization: Using peels and leftovers to create circular economy models.

Hybrid Nanomaterials: Combining fruit-based nanoparticles with polymers or drugs for multifunctional applications.

Regulatory Frameworks: Establishing biosafety

and eco-toxicology guidelines.

Public Awareness and Education: Informing society about the green potential of nanotechnology.

Conclusion

The use of fruits and vegetables in nanoparticle synthesis represents a paradigm shift in green nanotechnology. This approach not only reduces the environmental burden associated with chemical synthesis but also adds value to agricultural and kitchen waste. By harnessing the rich phytochemistry of everyday produce, we can create nanoparticles with high efficacy and broad applications across medicine, environment, and industry. While there are still challenges to address, the prospects for expanding this green frontier are both promising and exciting. As research deepens and interdisciplinary collaboration grows, fruit- and vegetable-derived nanoparticles may well become standard tools in sustainable innovation.

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Waste Management and Utilization in Flower Crops

Seema Thakre, U. V. Raut, S. A. Badge, Pallavi Thakre and Aditya Thakre

Abstract

The exponential growth of the floriculture industry has significantly increased the generation of flower waste across cultivation, marketing, and consumer stages. While often overlooked, this waste poses serious environmental challenges if not managed properly. However, it also presents opportunities for value addition and sustainable resource use. This article explores the major sources of flower waste, current challenges in waste management, and various eco-friendly utilization methods including composting, biogas generation, natural dye extraction, and cosmetic applications. It highlights successful case studies and emphasizes the need for policy support, community engagement, and technological innovation to build a circular economy around flower crop waste. With an integrated approach, the floriculture sector can move towards zero waste and contribute to ecological balance, rural development, and green entrepreneurship.

Introduction

The floriculture industry has witnessed exponential growth over the past few decades, fueled by rising global demand for flowers used in religious ceremonies, decorations, events, perfumes, and cosmetic products. In India, flower cultivation is a prominent segment of horticulture, with major crops including rose, marigold, jasmine, tuberose, chrysanthemum and gladiolus. However, with this increasing cultivation and commercialization of flower crops comes an often overlooked consequence: massive flower waste generation.

Managing and utilizing this waste sustainably is critical for environmental protection, resource conservation, and value addition.

Understanding Flower Waste and Its Sources:

Waste in flower crop production occurs at several stages, from cultivation to consumption. Field waste includes leaves, stems, pruned parts, and damaged flowers. Post-harvest waste comprises flowers that do not meet aesthetic standards, wilted blooms, and trimmings during packaging. Market and consumer-level waste involves unsold flowers, offerings from temples, garlands, bouquets, and floral decorations

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discarded after events. These residues are typically biodegradable but if not handled correctly, they contribute to environmental pollution, foul odor, and disease outbreaks. The sheer volume of flower waste is staggering. In major cities and temple towns, tonnes of floral waste are dumped daily into landfills or water bodies, disrupting ecosystems. Ironically, flowers symbols of purity and devotion become pollutants. Yet, this same waste is rich in nutrients, essential oils, pigments, and organic matter that can be effectively transformed into valuable products.

Challenges in Flower Waste Management: The primary challenge lies in the lack of awareness and infrastructure for proper waste collection, segregation and processing. Many urban and rural local bodies do not have separate systems for organic waste, let alone floral waste. As a result, flowers get mixed with general garbage, making them difficult to utilize. Additionally, the perishable nature of flowers limits their shelf life, necessitating prompt handling and processing. Societal attitudes also contribute to the problem. People are accustomed to discarding flowers after use, unaware of their potential reuse. Moreover, informal waste collectors rarely prioritize floral waste due to its low economic return unless value-adding systems are in place. Bridging this gap requires a combined effort of policy, technology, and community engagement.

Composting and Vermicomposting of Flower Waste: One of the most viable and eco-friendly ways to manage flower waste is composting. Floral waste, when decomposed with other organic residues,

results in nutrient-rich compost that enhances soil fertility. Flowers like marigold, rose and chrysanthemum decompose efficiently and contain essential micronutrients and organic carbon beneficial for soil health. Vermicomposting offers an enhanced form of composting, where earthworms such as *Eisenia fetida* are used to convert floral waste into vermicompost. This process not only reduces the volume of waste but produces a high-quality biofertilizer rich in beneficial microbes and enzymes. Vermicompost from flower waste improves plant growth, flowering, and resistance to pests and diseases. Many small-scale farmers and urban gardeners are adopting this method to close the loop in floriculture.

Biogas and Biofertilizer Production: Anaerobic digestion of floral waste in biogas plants is another sustainable method of waste utilization. The process yields methane-rich biogas, which can be used as a cooking fuel or to generate electricity. The residual slurry serves as a nutrient-rich biofertilizer. This technology is particularly effective in temples and flower markets where large quantities of waste are produced daily. Installing decentralized biogas units not only addresses waste management but also contributes to renewable energy production. Bio-enzymes and liquid fertilizers derived from flower waste are gaining popularity among organic farmers. Fermenting petals and floral residues with jaggery and citrus peels produces bio-enzymes that serve as natural cleaners, pest repellents, and plant growth stimulators. These products are cost-effective and

environmentally friendly alternatives to synthetic agrochemicals.

Extraction of Natural Dyes and Pigments: Floral waste contains a variety of pigments such as anthocyanins, carotenoids, and flavonoids that can be extracted and used as natural dyes. Marigold petals produce vibrant yellow and orange shades, hibiscus yields red hues, and rose petals offer soft pink to crimson colors. These natural dyes are biodegradable and safe for skin, making them suitable for textiles, crafts, cosmetics, and food coloring. Several research institutions and startups are working on solvent and enzymatic extraction methods to improve pigment recovery from floral waste. The revival of traditional dyeing techniques using flower-based dyes is creating niche markets for sustainable fashion and artisanal crafts.

Essential Oils and Aromatic Products: Despite being discarded, many flowers retain their aromatic compounds, which can be extracted to produce essential oils. Flowers like rose, jasmine, tuberose, and lavender are rich in volatile oils used in perfumery, cosmetics, and aromatherapy. Steam distillation of flower waste, though yielding less oil than fresh flowers, can still be economically viable when integrated into small-scale processing units. Aromatic powders, incense sticks, and potpourri made from dried flower petals are in demand in domestic and international markets. Floral waste-based incense sticks are especially popular as sustainable alternatives to chemically treated variants. They also offer livelihood opportunities to

women and self-help groups in rural areas.

Pharmaceutical and Cosmetic Applications:

Flower waste is a valuable source of bioactive compounds with therapeutic properties. Extracts from calendula, rose, hibiscus, and jasmine exhibit antimicrobial, anti-inflammatory, and antioxidant properties. These are incorporated into herbal formulations for skin care, wound healing, and stress relief. The cosmetic industry is increasingly exploring flower waste as a source of natural ingredients for creams, lotions, oils, and face packs. Academic research has supported the development of phytochemical extraction methods to isolate beneficial compounds from flower waste. Integrating such knowledge with industrial processing can lead to the development of high-value nutraceuticals and wellness products.

Temple Waste to Value-Added Products: Religious places are among the highest generators of flower waste. In cities like Nagpur, Shirdi, Shegaon, Varanasi, Kolkata, and Chennai, tons of floral offerings are discarded daily. Innovative startups have emerged to address this issue by collecting temple waste and converting it into eco-products such as incense sticks, compost, bio-leather, and decorative items. The success of such models depends on efficient collection systems, community participation, and market linkage. By involving temple authorities, waste collectors, and local artisans, a circular economy around religious flower waste can be established. Some initiatives also engage school children and volunteers to spread

awareness and promote waste-to-value education.

Policy Framework and Institutional Support: For flower waste management to be scaled effectively, supportive policy frameworks are essential. Government agencies should promote segregation of floral waste at source and provide incentives for decentralized composting and biogas units. Municipal bodies can collaborate with private players and NGOs to establish flower waste processing hubs in urban markets. The National Horticulture Mission, Ministry of New and Renewable Energy, and urban development schemes can incorporate floral waste management as a focus area. Providing financial support, training, and infrastructure to entrepreneurs and farmer groups will help mainstream flower waste utilization. Additionally, mandatory green procurement policies can create demand for compost, dyes, and eco-products made from flower waste. Research institutions should prioritize studies on floral waste characterization, processing technologies, and product development. Agricultural universities can establish incubation centers to promote startups in this field. Curriculum in horticulture and environmental sciences should include waste management modules to foster innovation among youth.

Community Engagement and Awareness: Public participation is vital for the success of any waste management initiative. Campaigns to educate farmers, florists, consumers and religious institutions about the value of flower waste can lead to behavior change. Social media, workshops, and demonstration

projects are effective tools for awareness. Community-level models involving self-help groups, women's cooperatives, and local entrepreneurs have shown great success. These models not only solve the waste problem but empower marginalized sections with income-generating opportunities. The role of NGOs and civil society organizations is pivotal in mobilizing communities and ensuring inclusivity.

Future Prospects and Research Needs: With growing awareness about environmental sustainability and circular economy, the demand for flower waste-based products is expected to rise. Innovations in biotechnology, green chemistry, and process engineering will expand the range of products and improve economic feasibility. Hybrid systems integrating composting, oil extraction, dye recovery, and biogas production can optimize resource use. Digital platforms can connect producers of flower waste with processors and markets, creating efficient supply chains. Certification schemes for eco-products can boost consumer confidence and facilitate exports. There is also scope for international collaboration in research, technology transfer, and market development. In the long run, a holistic strategy involving policy support, technological innovation, institutional collaboration and community participation can transform the floral waste challenge into a green opportunity. By harnessing the hidden potential in petals, floriculture can become not only beautiful but sustainable as well.

Conclusion

Flower crops symbolize beauty, celebration, and life. However, the waste generated from these crops poses significant environmental challenges if left unaddressed. With thoughtful waste management and innovative utilization strategies, flower waste can be transformed into compost, energy, natural dyes, fragrances, and even health products. These interventions not only reduce the ecological footprint of floriculture but also create economic value and support rural livelihoods. As awareness grows and technology advances, the vision of a zero-waste floriculture industry is within reach. The future lies in seeing not just the blossom, but also the bloom beyond its end.

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Blue Roses: Mystery and Wonder

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Abstract

The blue rose has long captured human imagination, symbolizing the unattainable, the mysterious, and the fantastical. While roses naturally bloom in red, white, yellow, and pink, the absence of a true blue rose in nature has intrigued botanists, artists, and romantics alike. This article delves into the historical symbolism, botanical challenges, scientific breakthroughs, cultural representations, and modern-day developments related to blue roses. Through a journey spanning mythology, genetics, biotechnology, and global commerce, we explore how the quest for a blue rose reflects both our limitations and our ingenuity. Despite decades of effort, true blue pigmentation in roses remains elusive, keeping the allure of the blue rose intact. Yet, advancements in genetic engineering offer promising pathways, opening a new chapter in the story of this floral enigma.

Introduction: The Color that Nature Denied

The rose is one of the most cherished flowers worldwide, symbolizing love, passion, and beauty. Yet, among all the vibrant hues it flaunts, there is one color nature has never granted it: blue. This absence has not only ignited myths and inspired poetry but has also spurred decades of scientific exploration. The idea of a blue rose unattainable, ethereal, and otherworldly has been a muse for artists and a holy grail for horticulturists.

Historical Background and Symbolism: Blue roses have often appeared in literature and folklore as emblems of the impossible. In ancient Chinese tales, a suitor was tasked with bringing a blue rose to win a princess's hand knowing it was a demand he

could not fulfill. In the Victorian language of flowers (floriography), a blue rose stood for mystery and a love that could never be. Writers and poets, including Rudyard Kipling and Tennessee Williams, used blue roses to reflect themes of longing, sadness, or unattainable desires. In *The Glass Menagerie*, Laura's nickname "Blue Roses" highlights her fragility and distance from societal norms.

The Science of Rose Coloration: Roses naturally come in a range of colors due to the presence of pigments like anthocyanins (for reds and purples), carotenoids (for yellows), and flavonoids. The pigment delphinidin is responsible for true blue coloration in flowers such as violets and pansies.

However, roses lack the specific gene pathways

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needed to produce delphinidin, making a true blue rose biologically impossible through traditional breeding. Attempts to create blue roses by crossbreeding or dyeing white roses date back to the 19th century. While these methods resulted in lavender or purple shades, they never achieved a true blue.

The Genetic Breakthrough: Engineering Blue Roses: In the early 2000s, Japanese company Suntory, in collaboration with Australian biotechnology firm Florigene, genetically engineered a rose containing the delphinidin gene from a blue pansy. After years of research, they introduced the first genetically modified “blue rose” in 2004 and began commercial sales in 2009. However, the resulting flower named “Applause” was more lilac or mauve than blue. Still, it marked a major leap forward and demonstrated the power of synthetic biology in floriculture.

Cultural and Commercial Impact: The debut of a genetically modified blue rose made global headlines. In Japan, where the flower market holds cultural and emotional value, the blue rose was marketed as a symbol of miracle and dreams come true. Prices were steep initially over \$30 per stem yet the novelty found eager buyers. In the West, blue roses remain a curiosity, frequently dyed or spray-painted for events or romantic gestures. Their rarity and symbolism make them ideal for weddings, fantasy-themed events and high-end floral arrangements.

The Quest Continues: Are We Close to a True

Blue?

Despite scientific progress, the holygrail remains elusive. Even genetically modified blue roses contain only about 95% delphinidin, with the remaining 5% of other pigments shifting the final color toward purple. Achieving a “sky blue” rose would require suppressing all competing pigments a task far more complex than inserting a single gene. Researchers are now exploring CRISPR and other gene-editing tools to refine pigment pathways. Synthetic biology might soon allow for a completely new biosynthetic route that replicates the blueness seen in hydrangeas or butterfly peas.

Ethical Concerns and Public Perception: As with any genetically modified organism, blue roses raise questions around ecological safety, consumer acceptance, and biodiversity. Critics argue that genetically engineered flowers serve commercial purposes more than ecological or humanitarian ones. Public reaction varies by region. In Japan and Australia, the response has been largely positive. In Europe, where GMOs face stricter regulation and public skepticism, commercial acceptance is still a distant dream.

Blue Roses in Modern Media and Pop Culture: Blue roses continue to fascinate creators in film, anime, music, and digital art. In David Lynch’s *Twin Peaks*, blue roses symbolize supernatural phenomena. In K-pop and J-pop, blue roses often feature in lyrics and visuals to represent purity, desire, or sorrow. They are also popular motifs in tattoos and jewelry, where the symbolism remains open to inter-

pretation ranging from impossible love to spiritual transformation.

DIY and Artificial Blue Roses: Because true blue roses are rare and costly, florists often create faux versions by dyeing white roses. This method, though temporary, creates stunning results and is widely used in weddings and themed events. YouTube tutorials and TikTok videos on DIY blue roses have millions of views, showing how the flower continues to captivate the younger generation.

Blue Roses and Mental Health Symbolism: In recent years, the blue rose has become a symbol of neurodiversity, introversion, and mental health awareness. As a representation of the misunderstood or unseen, it resonates with communities seeking uniqueness and validation. Blue rose imagery is now part of advocacy campaigns and mindfulness tools.

Future Prospects: Beyond Blue Roses: The quest for the blue rose mirrors humanity's broader desire to transcend limitations. While we may not yet have a perfect blue rose, the research paves the way for customized flowers roses that change color, glow in the dark, or even release tailored scents. The blue rose, in this light, becomes a stepping stone toward the future of synthetic floriculture.

Conclusion

The blue rose is more than a floral oddity it is a mirror of our dreams, a testament to innovation, and a symbol of what lies just beyond reach. Its journey from myth to lab-grown marvel reveals the intersections of culture, science, and desire. As we move forward with biotechnology, perhaps one day

we will hold in our hands a sky-blue rose, born not of fantasy but of brilliant science.

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Synergistic Role of Mycorrhiza and Rhizobia in Legume Based Cropping Systems

K. C. Singh, Atheek Ur Rehaman H. M., Greena P. G., Ayesha Siddiqua and Naresh Jayavelu

Abstract

In sustainable agriculture, legume-based cropping systems are of immense value due to their capacity for biological nitrogen fixation and soil fertility improvement. Two key microbial allies in these systems are arbuscular mycorrhizal fungi (AMF) and rhizobia. Individually, each enhances plant growth, nutrient uptake, and stress tolerance. However, when they function together, a powerful synergy emerges boosting nodulation, nitrogen and phosphorus assimilation, root development, and overall crop productivity. This article explores the mechanisms, interactions, and real-world implications of this microbial partnership in legumes. With a focus on field-level evidence, underlying biology, and application in integrated nutrient management, this paper supports the integration of these beneficial microbes as a sustainable tool for enhancing legume productivity and soil health.

Introduction

Leguminous crops like chickpea, soybean, cowpea, and lentils are fundamental to global food systems. Beyond their dietary significance, legumes play a crucial ecological role in improving soil fertility. Central to this ability is their symbiotic relationship with *Rhizobium* spp., nitrogen-fixing bacteria that form root nodules and convert atmospheric nitrogen into plant-usable forms. In parallel, arbuscular mycorrhizal fungi (AMF), form-

ing symbiotic associations with plant roots, enhance phosphorus uptake and overall nutrient efficiency. When mycorrhiza and rhizobia co-exist in the rhizosphere, especially in legume-based cropping systems, they often exhibit synergistic interactions. This mutual reinforcement significantly boosts plant growth, nutrient acquisition, and resilience to abiotic stresses. With the global push toward sustainable farming practices and reducing chemical fertilizer usage, this synergy offers a low-cost, eco-friendly

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strategy for enhancing yields while improving soil health. This article explores how this tripartite association plant, rhizobia, and AMF can be harnessed for long-term agricultural sustainability.

Understanding the Microbial Players

Rhizobia: Natural Nitrogen Fixers: Rhizobia are soil bacteria that infect legume roots, forming nodules where they fix atmospheric nitrogen. This biological nitrogen fixation (BNF) provides a sustainable alternative to synthetic nitrogen fertilizers, reducing both environmental footprint and production cost.

Arbuscular Mycorrhizal Fungi (AMF): AMF form symbiotic associations with 80% of terrestrial plants, including legumes. They colonize root cortical cells and extend their hyphae into the soil, increasing the root's absorptive surface. In exchange for plant photosynthates, they enhance uptake of nutrients, especially phosphorus, zinc and micro-nutrients.

Mechanisms of Synergism in Legume Systems

Enhanced Nodulation and Nitrogen Fixation: Mycorrhizal colonization improves phosphorus availability, which is critical for nodulation and rhizobial activity. AMF indirectly promote higher nitrogen fixation by improving root health and metabolic activity in nodules.

Improved Phosphorus Uptake: Phosphorus is often a limiting nutrient in soils. While rhizobia focus on nitrogen, AMF bridge the phosphorus gap. Their hyphal networks efficiently scavenge phosphorus beyond the depletion zone of the roots,

benefiting overall plant metabolism.

Root Morphology and Soil Exploration: The dual presence of AMF and rhizobia leads to a more extensive root system with increased root hair density. This allows greater nutrient exploration and water uptake, especially in resource-limited conditions.

Hormonal and Molecular Interactions: Both rhizobia and AMF influence plant hormone levels particularly auxins and cytokinins that modulate root architecture and signalling. They also prime the plant's immune system, enhancing resistance to pathogens.

Field Evidence: Trials and Case Studies: Multiple field studies demonstrate improved growth parameters in legumes with dual inoculation of rhizobia and AMF:

- ✓ Soybean trials in Brazil showed a 25-30% increase in yield with combined inoculation.
- ✓ Chickpea research in India reported increased nodulation, phosphorus uptake, and pod number.
- ✓ Lentil trials in Nepal and Ethiopia showed better drought resistance and biomass production under dual inoculation.

These effects are often crop- and soil-specific, emphasizing the need for region-based formulations.

Role in Sustainable Agriculture

Reducing Chemical Fertilizer Dependency: Dual inoculation can significantly reduce the need for nitrogen and phosphorus fertilizers by up to 50% in some studies thereby reducing input costs and envir-

onmental pollution.

Promoting Soil Health and Microbial Diversity:

These symbioses enrich soil biodiversity and foster beneficial microbe populations. Their hyphal and root secretions stabilize soil aggregates, improving structure and water retention.

Enhancing Resilience to Climate Stress: Under drought, salinity, or heat stress, inoculated legumes have shown better tolerance due to improved osmotic adjustment, antioxidant production and root efficiency.

Limitations and Challenges

Despite their benefits, some practical issues limit widespread use:

- ✓ Inoculant inconsistency due to formulation quality
- ✓ Competition with native soil microbes
- ✓ Host specificity and compatibility
- ✓ Lack of awareness among smallholder farmers

Addressing these requires better biofertilizer standards, on-farm trials, and farmer training programs.

Future Perspectives

The integration of microbial consortia into Integrated Nutrient Management (INM) systems can redefine nutrient use in legumes. Research is also exploring:

- ✓ Genomic tools to identify super strains of rhizobia and AMF
- ✓ Co-inoculants for region-specific cropping systems
- ✓ Nano-formulated biofertilizers for better shelf

life and field performance

- ✓ Digital agriculture tools for precise inoculation and monitoring

With supportive policies and research investments, the synergistic use of rhizobia and AMF can revolutionize legume production.

Conclusion

The symbiotic alliance between mycorrhiza and rhizobia represents one of nature's most efficient partnerships one that can be harnessed to build resilient, low-input, and productive legume-based farming systems. By promoting nutrient cycling, reducing dependency on chemicals, and enhancing crop resilience, these microbes offer a sustainable path for future agriculture. Their combined use holds the key to food security, soil regeneration, and environmental health, particularly in the face of global climate change.

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Artificial Photosynthesis

Manoj Nazir, Vinayaka K. S. and D. Nagaraju

Introduction

Photosynthesis is a time-tested on the largest-scale, most essential and abundant solar energy conversion system on the planet. Photosynthetic plants and bacteria provide energy/fuel for majority of the biosphere, and generating 86% of the energy in form of fossil fuels being used today (Lewis and Nocera, 2006). Plants have unique property to harvest these photons with the help of photosynthetic pigments to generate assimilatory power of reduction of carbon into energy rich carbohydrates (Lal *et al.*, 2018). Effective light absorbers make it simple to capture solar energy, but it takes a tremendous amount of work to transform it into chemical energy. In order to lessen the depletion of fossil fuels, climate change, and issues linked to geopolitics, scientists are looking for ways to increase the efficiency (less than 1% in most cases) of solar energy gathering and conversion into chemical energy. For more than a decade, there has been discussion on the importance of applying the fundamental physics of natural photosynthesis to develop new designs for solar fuel production. However, lack of an efficient technology for generating solar fuels that can compete with fossil

fuel utilization makes it quintessential. Inspired by the natural photosynthesis, where chlorophyll molecule absorbs light and reduce carbon dioxide into carbohydrate, light generated electrons are used to bring about chemical reactions which in turn is stored in the form of energy rich chemical bonds. Natural photosynthesis is multiple-step phenomenon which is being mimicked in the process known as artificial photosynthesis (Wendell, 2010). The success of photosynthesis as an energy-generating and-storage system stems from the fact that the raw materials and power needed for the synthesis of biomass are available in almost unlimited amounts; sunlight, water and CO₂. At the heart of the photosynthetic process is the splitting of water by sunlight into oxygen and hydrogen equivalents. The oxygen is released into the atmosphere where it is available for living organisms to breathe and for burning fuels to drive our technologies. The hydrogen equivalents are used to reduce CO₂ to sugars and other organic molecules of various types. When we burn fuels (fossil, biomass and other biofuels) to release energy, we are simply combining the 'hydrogen' stored in these organic molecules

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with atmospheric oxygen to form water, so completing a cycle started millions of years ago. Similarly, energy is also released from the organic molecules which constitute our food, when they are metabolized within our bodies by the process of respiration. Thus, in the biological world, photosynthesis brings about the splitting of water into oxygen and 'hydrogen', whereas respiration is the reverse, combining oxygen and hydrogen in a carefully controlled and highly efficient way so as to create metabolic energy.

The Science of Artificial Photosynthesis

Photosynthesis is a biochemical process carried out by plants, algae, and certain bacteria to convert light energy into chemical energy. During this process, chlorophyll absorbs sunlight, which drives the conversion of carbon dioxide and water into glucose and oxygen. Artificial photosynthesis attempts to mimic this natural process using synthetic materials and engineered systems to achieve the same energy transformation. There are two primary approaches to artificial photosynthesis:

Photoelectrochemical Systems: These systems use semiconductor materials, such as titanium dioxide or perovskite-based catalysts, to absorb sunlight and drive water-splitting reactions. The result is the production of hydrogen and oxygen gases, with hydrogen serving as an energy carrier that can be used to synthesize organic compounds.

Biochemical and Synthetic Biology Approaches: Scientists are also engineering microorganisms and synthetic enzymes that can capture carbon dioxide

and convert it into useful organic molecules like carbohydrates, proteins, and fats. These biocatalytic systems are inspired by the efficiency of natural enzymatic pathways in photosynthetic organisms. Development of catalysts that effectively split water molecules and absorb carbon dioxide has advanced significantly. For instance, catalysts based on cobalt and ruthenium have demonstrated potential in raising the effectiveness of artificial photo-synthesis systems. Additionally, scientists are able to improve carbon fixation and maximize energy conversion rates thanks to developments in nano-technology and bioengineering.

Potential Benefits of Artificial Photosynthesis

Sustainability and Resource Conservation: Artificial photosynthesis doesn't require a lot of fresh-water, chemicals, or arable land like conventional farming does. This could lessen habitat loss brought on by agricultural expansion and aid in the conservation of natural ecosystems.

Climate Change Mitigation: The technology captures and utilizes carbon dioxide from the atmosphere, potentially reducing greenhouse gas concentrations. If successfully integrated into food production, artificial photosynthesis could play a crucial role in addressing climate change.

Year-Round, Location-Independent Food Production: Artificial photosynthesis could enable food production in extreme environments, such as deserts, urban areas, or even space. Bioreactors and controlled environment facilities could allow for continuous production, independent of weather conditions or

Soil quality.

Reduced Dependency on Chemical Inputs:

Conventional farming relies heavily on chemical fertilizers and pesticides, which contribute to soil degradation and water pollution. Artificial photosynthesis eliminates the need for such inputs, promoting cleaner and safer food production.

Food Security and Global Accessibility: With the ability to produce essential nutrients without traditional farming, artificial photosynthesis could help address food shortages in regions affected by land degradation, climate extremes, or geopolitical instability.

Challenges and Limitations

Despite its potential, artificial photosynthesis is still in its early stages and faces several challenges before it can be a viable alternative to conventional farming:

Technological Maturity: Current artificial photosynthesis systems are still in experimental stages, with efficiencies much lower than natural photosynthesis. While some prototypes have shown promise, large-scale implementation remains a distant goal.

High Costs of Development and Implementation:

The materials and infrastructure required for artificial photosynthesis are expensive, limiting their commercial viability. Scaling up these technologies while keeping costs competitive with conventional agriculture is a major challenge.

Energy Requirements: Artificial photosynthesis relies on solar energy, but additional energy inputs,

such as electricity, are often required to drive chemical reactions. To maintain sustainability, these systems must be powered by renewable energy sources.

Public Acceptance and Consumer Perception:

The idea of consuming synthetic or lab-grown food may face resistance from consumers who prefer natural, farm-grown products. Public education and regulatory approval will be essential in gaining acceptance.

Nutritional Quality and Safety: While artificial photosynthesis can generate basic organic compounds, ensuring that these synthetic foods provide the same nutritional benefits as natural foods remains a challenge. Research is needed to understand the long-term health impacts of consuming lab produced nutrients.

Future of Artificial Photosynthesis and Agriculture

Rather than completely replacing conventional farming, artificial photosynthesis is more likely to serve as a complementary technology. In the near future, artificial photosynthesis could be used to produce specific food components, such as proteins, amino acids, or essential fatty acids, which can be incorporated into traditional diets. This hybrid approach would allow for a gradual transition without disrupting existing agricultural systems. As technological advancements continue and production costs decrease, artificial photosynthesis may play a crucial role in addressing niche challenges, such as producing food in space or regions with extreme

environmental conditions. Collaborations between scientists, governments, and industry leaders will be essential in driving research, investment, and policy development to integrate artificial photosynthesis into sustainable food systems. Additionally, policy-makers must establish regulatory frameworks to ensure the safe adoption of synthetic food products while promoting public awareness and acceptance. If successfully developed and implemented, artificial photosynthesis could be a groundbreaking innovation in the quest to achieve global food security without further straining natural resources.

Conclusion

An innovative method of producing food, artificial photosynthesis provides a sustainable substitute for traditional farming. By lowering environmental impact, addressing food security, and minimizing climate change, it has the potential to augment and improve food systems, even though it is unlikely to completely replace traditional farming in the near future. Significant obstacles, such as those related to cost reduction, public perception, regulatory permissions, and technology scalability, must be addressed before its full potential can be realized. An innovative method of producing food, artificial photosynthesis provides a sustainable substitute for traditional farming. By lowering environmental impact, addressing food security, and minimizing climate change, it has the potential to augment and improve food systems, even though it is unlikely to completely replace traditional farming in the near future. Significant obstacles, such as those

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Role of Phytoalexins in Plant Defence

N. Anil Kumar, Sandeep Sudhakar Wagh and Priya Kashyap

Introduction

Plants face a serious threat from the plant pathogens that are mainly of microbial origin. The plants, therefore, evolved several mechanisms for defending themselves from the invading pathogens that include production of PR proteins (Sharma *et al.*, 2021), production of thick cuticular wax and several other kinds of structural defenses (Agrios, 2005), etc. Besides this, plants also produce some antimicrobial substances upon pathogen invasion that helps in defending them against the pathogens. Furthermore, the indiscriminate and excessive use of fungicides in crops is a major cause of the development of resistant pathogens populations, resulting in the application of high concentrations of these fungicides and the consequent increase in toxic residues in foodstuffs. To improve this situation, researchers are actively exploring alternative methods of disease and pest control. Therefore, plants evolved many mechanisms to defend themselves from invading pathogens, producing thick cuticular wax and other forms of structural defences. The Greek words phyton, which means plant, and alexos, which means defend, refer to the phytoalexins, which are absent from healthy

plants and have a function in plant defense. Since elicitors, which are the particular compounds, induce the manufacture of phytoalexins, these are known as species-specific substances. Following a few hours or days of the pathogen attack, the impacted plants release trace levels of phytoalexins, which set off their defense mechanism. It was found that *Solanum tuberosum* inoculated with an incompatible race of *Phytophthora infestans* induced the synthesis of a putative defense-related metabolite, which resulted into the resistance toward that provided resistance to a compatible race of the pathogen (Muller *et al.* 1939). In 1940, these induced putative antimicrobials were termed as phytoalexins, whose production was found to be triggered in response to *P. infestans* attack in potato and therefore, the term phytoalexins was first time used for describing such antimicrobial substances. The phytoalexins have been described thereafter as a diverse group of plant-based antimicrobial compounds with low molecular weights, which can be synthesized/ accumulated in plants in response to their exposure to the pathogenic microorganisms. The phytoalexins and phytoanticipins are distinguished on the basis of their production and

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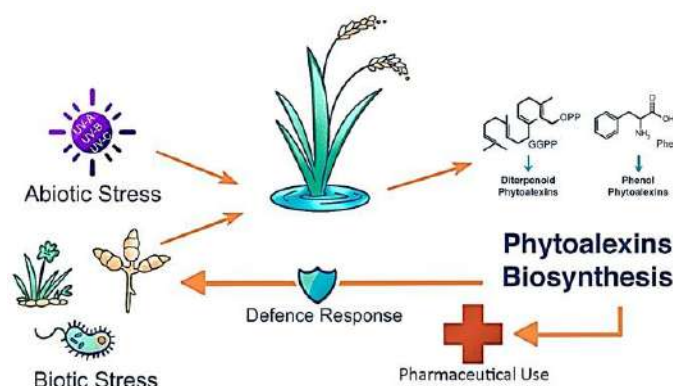
response toward the invading pathogens. Although their production may seem arbitrary, this distinction is based on fundamental differences in the responses of the host plants to the microbial invasions. Phytoalexins play a role in plant disease resistance, when a pathogen induces an active response (that is stimulated upon exposure of plant pathogen); whereas a phytoanticipin plays a role in plant disease resistance response only through passive interaction (even without the pathogen exposure).

Origin of Phytoalexins

The concept of plant phytoalexins was introduced about 70 years ago from potato tuber tissues infected by *Solanum tuberosum* i.e. *Phytophthora infestans*. The tuber tissue, in turn, produced certain chemicals, referred as phytoalexins, that inhibited the growth of microbes and protected the plant from later infections. Muller & Borger first submitted a paper on this hypothesis, then they experimented with another plant and demonstrated that plants produce such antimicrobial compounds when infected with pathogens.

Table 1: Phytoalexins from various plant families

Family	Phytoalexins
Malvaceae	Terpenoids, gossypol
Solanaceae	Capsidiol, scopoletin
Brassicaceae	Camalexin, Brassinin, spiobrasinin, brassilexin, rutalexin
Leguminosae	Isoflavones, Isoflavanones, Isoflavans, Coumestans, phaseollin, glyceollin and maackiain
Poaceae	Sakuranetin, phytocassanes, phenylamides
Apiaceae	Falcarinol, Xanthotoxin, 6-methoxymellein
Eupobiaceae	Casbene
Rutaceae	Methylated phenolic compounds/xanthoxylin
Compositae	Polyacetylenes/safynol
Orchidaceae	Loroglossol
Vitaceae	Resveratrol, viniferins, piceids, pterostilbene



Phytoalexins from Two Model Plants

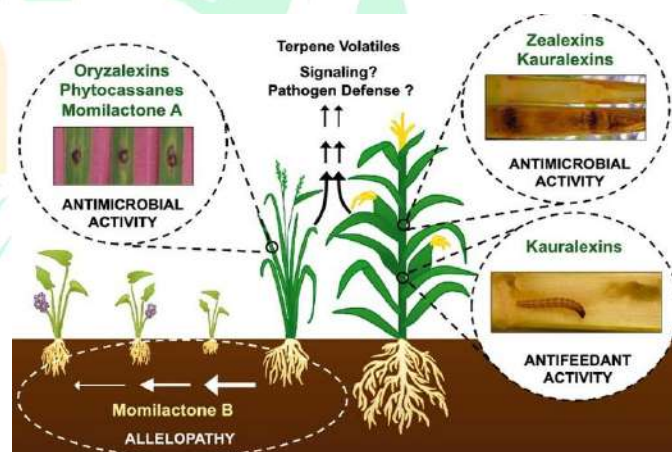
In the recent years, our knowledge on plant defense and disease resistance are primarily based on the experimentation on model plant species. In this regard, Arabidopsis and rice have been two excellent model plants for plant defense at molecular level; however, the recent studies have also been using some alternative model plants. In the subsequent sections, we have tried to compile the information available on the phytoalexins of these two model plants available till date, to the best of our knowledge.

Arabidopsis: *Arabidopsis thaliana* is a model plant of family Brassicaceae. In this plant, tryptophan-derived metabolites like an indolic phytoalexin, i.e., camalexin and indolic glucosinolates, indole-3-carboxylic acid derivatives, indole-3-carbonyl nitriles, etc., have been reported as end products of microbe-induced metabolic pathways (Pastorczyk *et al.*, 2020); however, the major phytoalexin found in *A. thaliana* is camalexin, which has been extensively studied since its discovery. Tsuji *et al.* (1992) reported the accumulation of a sulfur-containing indole derivative phytoalexin, i.e., camalexin (3-thiazol-20-yl-indole), upon the inoculation of leaves

of *A. thaliana* with the wheat pathogen, *Pseudomonas syringae* pv *syringae*, leading to a hypersensitive reaction.

Phytoalexin in Disease resistance: Phytoalexin concentrates at infection sites and they inhibit the growth of fungi and bacteria in vitro therefore, it is logical to contemplate them as potential plant defence compounds in contradiction of diseases caused by fungi and bacteria. Phytoalexins are considerably lesser noxious than chemical fungicides. Phytoalexin fungi toxicity has clearly showed the inhibition of germ-tube elongation, radial mycelial growth and mycelia dry weight growth, as best elucidated by the action of resveratrol on *B. cinerea*, the pivotal causal agent for gray mold in grapevine. Phytoalexins may also exercise some effects on the cytological, physiological and morphological characteristics of fungal cells. The activity of three phytoalexins from the Solanaceae family (rishitin, phytuberin, solavetivone) on three phytophthora species caused the damage in the motility of zoospores, rounding of the cells associated with more or less level of swelling, cytoplasmic granulation and bursting of cell membrane. Concerning the accumulation of pisatin in pea and phaseolin in green bean, it was apparent that the phytoalexins accumulated to fungi toxic concentrations not only in inoculum droplets placed on opened pea or bean pods but also in the tissues immediately below the inoculum droplets. Asymmetric growth of the germ tube resulting in the production of “curved-germ tubes” has also been observed in *B. cinerea* conidia

treated with sub-lethal doses of resveratrol. This cytological abnormality suggests that stilbenic compounds may interact with tubulin polymerization, the mode of action of many synthetic fungicides and anticancer agents. Moreover, phytoalexins may affect glucose uptake by fungal cells as reported in the interactions between phaseollin or kievitone and *Rhizoctonia solani*. Conidia of *B. cinerea* showed a complete disorganization of mitochondria and disruption of the plasma membrane upon treatment with the stilbene phytoalexins, resveratrol and pterostilbene. Camalexin has recently been involved in the induction of fungal apoptotic programmed cell death in *B. cinerea* (Shlezinger *et al.*, 2011).



Conclusion

In conclusion, phytoalexins are only one component of the complex mechanisms for disease resistance in plants. Studies on phytoalexins alone have contributed a great deal to plant biochemistry and molecular biology. Phytoalexin production and accumulation occur in healthy plant cells surrounding wounded or infected cells and are stimulated by alarm substances produced and released by the damaged cells and diffusing into the adjacent healthy

cells. Phytoalexins are not produced during compatible biotrophic infections. Most phytoalexin elicitors are generally high molecular weight substances that are constituents of the fungal cell wall, such as glucans, chitosan, glycoproteins and polysaccharides. The elicitor molecules are released from the fungal cell wall by host plant enzymes.

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Agriculture and its Role in Economic Development

Anshika Jain, Sarita Yadav and Aparna Gogoi

Introduction

India is principally agricultural country. Agriculture is the only means of living for almost two-thirds of the employed class in India. It constitutes the most significant part of Indian Economy. Agriculture, along with its allied sectors, is unquestionably the largest livelihood provider in India and most key industries depend upon the sector for their inputs. Agriculture in India has undergone rapid transformation in the past two decades; the policies of globalization and liberalization have opened up new avenues for agricultural modernization. This has led to not only commercialization and diversification, but also triggered various technological and institutional innovations owing to investments in sector. Both Agriculture and Industrial sector are considered as important ingredients particularly in the initial stages of economic development of a developing country. Agriculture has played a key role in the development of human civilization. Until the Industrial Revolution the majority of the population depended in agriculture for their survival. Historically and traditionally Indian economy has been considered as an agrarian economy with $3/4^{\text{th}}$ of its population living in villages having agriculture and allied activities as

their prime occupation. Since more than half of India's population depends on agriculture for both food and a living, the majority of people there place a higher value on it. The Indian economy is still seen as an agrarian one even after 60 years of independence. According to Sastry (2003), the input-output test indicates that the agricultural sector influences the economy's overall growth rate through demand links with other sectors, even though the service sector's share of GDP has increased significantly over time. Others believe that industry is more significant for India because it boosts economic growth more quickly and contributes more to GDP than agriculture. GDP is the primary measure of economic growth and demonstrates how well an economy is performing. There is no doubt that both the sectors are very much essential for Indian economy. Here the question arise "Agriculture versus Industry, which contributes more to Indian economy?" The question is in debate since last two decades. Any rational being would agree that it is essential to maintain an adequate balance of both sectors to exist in today's fast changing world. And to cope with the changing world, one must have to gradually move towards more industrialization because it will bring the possibility of higher growth

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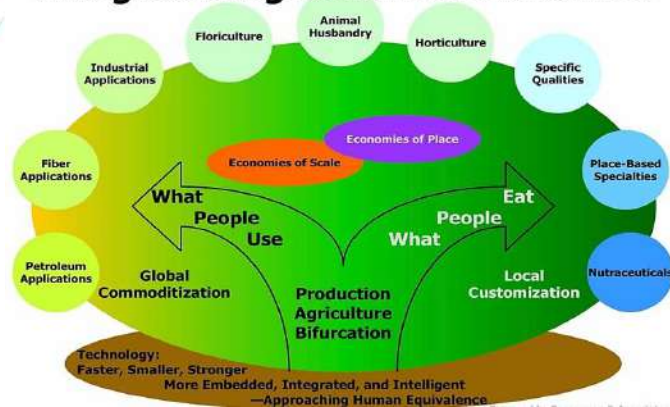
for the economy in future. At the same time, there has been a major discussion going on importance of agriculture. No one denying the fact that India has been an agrarian economy. Agriculture is the backbone of Indian economy. To ensure food security and development of the society, we have to depend on agriculture. In the Indian context, some studies broadly highlight that the sectoral composition of three sectors in economic growth has important implications. The results also indicate that sectoral distribution of growth rates has a strong impact on poverty reduction.

Food Security and Sustenance: Food security is one of agriculture's most important functions. Human survival and well-being depend on a steady and consistent source of food. Population health and nutritional condition are directly impacted by agricultural output. Countries can improve the quality of life for a significant percentage of their population by tackling food security issues, reducing hunger and combating malnutrition through increased agricultural efficiency.

Economic Growth and Development: Agriculture plays a crucial role in the life of an economy. It is the backbone of our economic system. It is not only provides food and raw material but also employment opportunities to more than half of India's population. It is considered as an agrarian economy where nearly 70 percent of its total population directly or indirectly involved in agriculture for their Survival. It provides food security to all the citizens of India. Agriculture is the main source of livelihood for a labor surplus

country like India as it provides direct employment to 52.1 percent of the total workforce. One of the main forces behind economic expansion is agriculture. For a large portion of the global workforce, especially in underdeveloped nations where many people rely on agriculture for a living, it offers employment options. Higher rural earnings as a result of increased agricultural production boost demand for goods and services across the economy. Additionally, agriculture is a key component of many other sectors. It supplies vital raw ingredients for the manufacturing of textiles, biodiesel, and food processing. Cotton, for instance, helps the textile sector, whereas corn and sugarcane are used to produce bioethanol. Economic diversification and steady growth are encouraged by the relationship between industry and agriculture.

Integrated Agricultural Economies



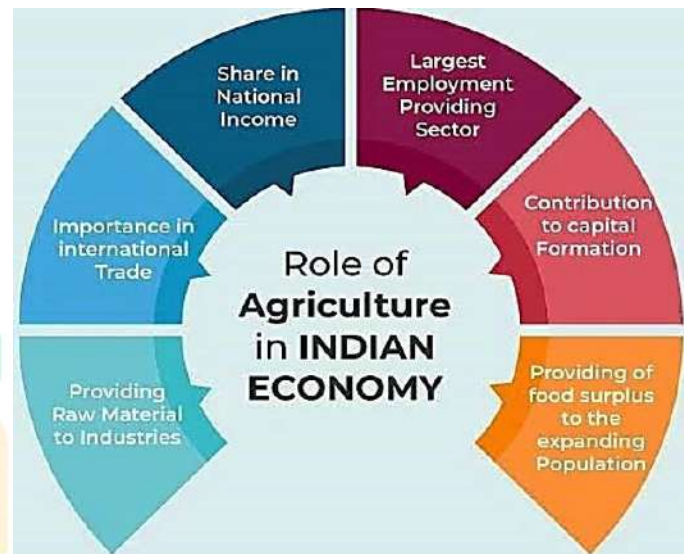
Product Contribution: Developing economies largely rely on agriculture to sustain their populations. While some resource-rich nations like Malaysia and Saudi Arabia generate sufficient foreign exchange to import food, most developing countries lack such revenue streams. Consequently, they depend on domestic agricultural production to meet

consumer demand and sustain economic stability. Farmers in these economies must produce surplus food beyond their own needs to support urban populations. As industrial and service sectors expand, agricultural output and productivity must also increase to sustain economic growth and ensure food security for a growing workforce.

Market Contribution: Agriculture plays a crucial role in stimulating economic growth by generating income for farmers, which in turn fuels demand for manufactured goods. Increased agricultural productivity leads to higher rural incomes, which are then spent on tools, equipment, and consumer goods, thereby stimulating industrial production. For example, farmers cultivating cash crops like cotton or sugar generate income that enables them to purchase manufactured products. Similarly, surplus grain production enhances farmers' purchasing power, further driving industrial demand. Conversely, a decline in agricultural productivity can negatively impact industrial growth, as lower farm incomes reduce demand for manufactured goods.

Implication of E-governance on the Indian farmers' ease of living: Presently, information and communication technology (ICT) and mobile-enabled agricultural services serve as tools for delivering extension services via mobile phone infrastructure and raising farmer awareness. In India, the rising penetration of mobile networks and devices present a great deal of opportunity (Mittal *et al.*, 2010). But very first challenge is whether the farmers effectively adapt to such technologies, given

the impediments of digital literacy, small holding size, and poor infrastructure, that often leads to poor technological acceptability. Further, traditional Indian market places, for example, are controlled by market intermediaries and dealers, who determine the bulk of prices and on whom the majority of farmers rely for information (Pahwa, 2020).



Verticals of research and developments in the Indian agricultural sector: Small nations like Israel and the Netherlands have benefited recently from the adoption of cutting-edge technologies. In smallholder agricultural systems, modern technology like sensors, imaging, and automation are still not commonly adopted for a number of reasons, including the associated economics. It is necessary to build digital solutions for smallholder farmers in a centralized manner while maintaining realistic economics. At the moment, sensors are expensive enough to be vulnerable to theft in these regions. In addition, their battery life is short, and energy availability may be a constraint. Therefore, there is a growing need to develop technologies that can

complete these jobs on inexpensive devices, which is only possible if the technology is developed domestically (OECD, 2011).

Conclusion

India's economy is significantly driven by the agriculture and trade sectors, which play a crucial role to encourage the expansion of the marketplace. On the other hand, there is a dearth of scientific and philosophical information about the influence that farming, the utilization of clean energy and trade accessibility has on carbon dioxide emissions. Additionally, the association among independent variables and CO₂ emissions has yielded mixed theoretical and empirical findings. Fossil fuel usage in the agricultural sector results in a significant spike in CO₂ emissions. Renewable energy is crucial for the agriculture industry. Implementing it is highly recommended to incorporate rooftop solar power mechanisms, offshore wind electricity, effectiveness watering techniques, training programmers, and financial support in the agriculture sector to promote environmental sustainability. Policymakers should prioritize emphasizing the success of transitioning from fossil fuel energy to clean energy. This can be achieved through increased Securing financing for advancement and research initiatives, while also enhancing regulations and legislation. In order to mitigate the effects of trade openness and the impact of economic expansion on ecological sustainability, it is essential to promote the development of environmentally friendly industries that can facilitate the transfer of clean technology knowledge across all

sectors of the economy.



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Seed Priming

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Introduction

Environmental pollution and abiotic stresses are major global problems affecting seed germination, emergence and vigour of seedling and ultimately crop yield (Carvalho *et al.*, 2011). These unfavorable conditions have a severe impact in many agricultural areas especially arid and semi-arid lands. Abiotic stresses affect the plant growth and crop yield by delaying the start of germination and reducing its rate of growth (Maasoumeh and Mohammad, 2014). It also affects soil biota resulting in economic losses. Another constraint in crop yield is the less availability of nutrients in the soil. India being an agricultural country urges the need of simple, effective and manageable technology to enhance establishment of crops under all environmental conditions. Different techniques can be used to enhance crop yield of which, seed priming is the simple and suitable technique to synchronise seed germination, increase emergence and establishment in the farm. Seed priming technique can aid the farmers to reduce the excess use of fertilizers, enhance crop yield by synchronized seed germination and induce systemic resistance in plants. Seed priming treatment is done before sowing seeds, which involves hydration of seeds plentiful enough

to enable metabolic events before germination to take place, although preventing radicle emergence to occur. For many years, researchers have looked for ways to enhance crop species' growth and development. Successful crop establishment requires rapid germination and emergence, which may be facilitated by seed priming. A useful technique for achieving high vigor and accelerating and uniform emergence, seed priming improves stand establishment and yield. Using this straightforward and inexpensive hydration method, seeds are partially soaked until pre-germination metabolic processes begin without actual germination, and they are then re-dried until they are almost their initial dry weight. For improved crop stand and increased yields in a variety of crops, seed priming is used. Various studies have been carried out to reduce the period between sowing to emergence as this play a key role in crop production. One of the important developments in this area has been the seed priming technique. The theory of seed priming was first proposed by Heydecker (1973). Seed priming is an effective technology to enhance rapid and uniform emergence and to achieve high vigour, leading to better stand establishment and yield. It is a simple and low cost hydration technique in which seeds are

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partially hydrated to a point where pre-germination metabolic activities start without actual germination, and then re-dried until close to the original dry weight. Rehman *et al.* (2011) reported that seed priming is a cost effective technology that can enhance early crop growth leading to earlier and more uniform stand with yield associated benefits in many field crops including oilseeds.

Mechanisms of Seed Priming

Generally, the germination of seeds takes three phases. (1) Phase I: seed imbibition phase, in which quick water uptake involves in apoplastic spaces through forces driven by seed. (2) Phase II: Activation phase, in which re-establishment of metabolic activities (protein synthesis takes place) and repairing process and (3) Phase III: Germination phase, where cell elongation and radical emergence occurs. Hydration remains stable in phase II. In the case of priming, I and II phase occurs but not allowing seeds to enter phase III. Before ending of phase II germination remains a reversible process because seeds may be dried again and remain alive during storage which re-initiate germination under suitable conditions.

Techniques of Seed Priming

Nowadays different priming techniques are developing to provide better seed quality such as hydro-priming, halo priming, osmo-priming, matrix priming, osmohardening, on farm priming, hormone or growth enhancer priming, micronutrient seed priming (Nutripriming), biopriming or seed treatment with micro-organisms, e.g. *Pseudomonas*

aureofaciens, *Trichoderma* spp. etc and nanoparticle priming or coating seeds with nanoparticles(NPs). Each crop requires specific and optimised priming technique. Optimization includes various parameters such as time required for treatment, priming or coating substance, seed vigour and storage conditions (temperature, moisture, oxygen requirement etc.) which are standardized by trial and error for each cultivar.

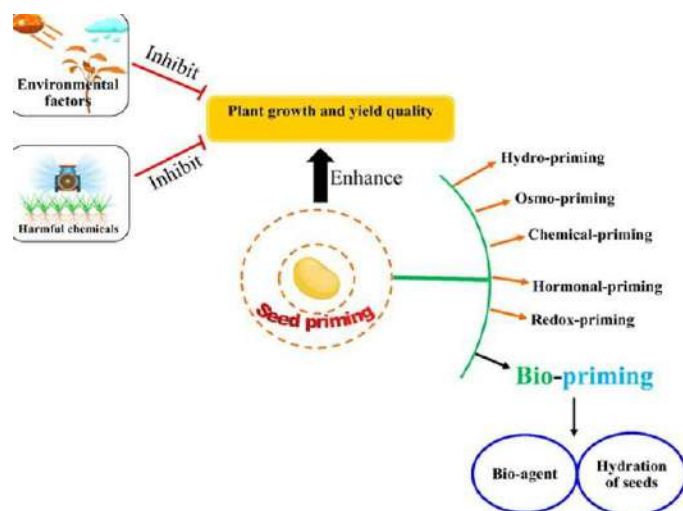
Seed priming tests in lab



Hydro-priming: Priming with water process known as “hydro-priming” involves soaking seeds in water, drying them to dehydrate them, and then planting them the following day. This speeds up the germination process and increases the strength and growth of seedlings. Increased quantity of grains/plant/unit area from low vigour seeds on comparison with high vigour seeds and also restored the quality of aged and damaged seeds enhancing the production in field. It also increased germination percentage and seedling emergence which cause productive use of resources (soil, light) to increase the amount of grains. Decrease in seed vigour is an indication of electrolyte leaching due to an increase in membrane permeability.

Osmotic Priming/ Halo Priming: Osmotic Priming or Halo Priming refers to the soaking of Seeds in a

solution of inorganic salts. In Osmotic Priming, seeds are soaked in solutions containing chemicals such as Polyethylene glycol (PEG), Potassium nitrate (KNO_3), Sodium chloride (NaCl), Potassium chloride (KCl), Mannitol, Glycerol, Sorbitol. Priming with salt solutions known as Halo priming. Osmotic Priming of seeds helps in the improvement of germination of Seed, Seedling emergence, establishment and final crop yield in salt-affected soils.



Solid matrix priming: It involves the incubation of seeds in a solid, insoluble matrix, such as vermiculite, another high water-absorbent polymer, with a limited amount of water, allowing for slow imbibition.

Bio-priming: Biopriming of seeds denotes standard tactic for introduction of disease resistance via bio control agents. Priming of seeds with helpful microorganisms and bio control means has been testified more proficiently for the management of diseases and pests as equated to other available methodologies (Prabha *et al.*, 2019). The seed biopriming is a recently adapted method of seed

priming. Seed priming is a pre-sowing treatment which leads to a physiological state that allows seed to germinate more proficiently. Numerous instances of biopriming with various biological agents have shown positive impact against a diverse group of pathogens, such as *Fusarium*, *Verticillium*, *Colletotrichum*, *Rhizoctonia* and *Sclerotium* (Rajput *et al.*, 2021).

Hormonal priming: Hormonal priming refers to treating seeds in hormones such as GA_3 , salicylic acid, ascorbate, kinetin, Jasmonic acid etc. which helps in promoting seedling growth. Gibberellic acid priming influence on growth and biochemical parameters of chickpea DCP 92-3 cultivar was studied by Mazid (2014). Chickpea seeds primed with four different concentrations of GA_3 showed significant increase after 90 and 100 days of sowing with best results obtained at 10-6 M concentration soaked for 8 hrs. Biochemical (protein content, carbonic anhydrase (CA) activity) and growth parameters (seed yield and leaf area/plant, pod number and shoot length) were also enhanced. Gibberellins are known to regulate developmental and physiological processes such as germination, stem, leaf growth, synthesis of food, transporting and partitioning it, stimulating transcription of hydrolytic enzymes' mRNA in various plants.

Advantages of Seed Priming

- ✓ Faster speed of germination.
- ✓ Increases germination rate.
- ✓ Enables seed to germinate and emerge even under adverse agro-climatic conditions i.e. stress

conditions.

- ✓ Improves uniformity to optimise harvesting efficiency and enhance yield potential.
- ✓ Seed performance improved under stress conditions.
- ✓ Protect seed from seed-borne fungi.

Conclusion

Germination and seedling emergence are the critical stages in the plant life cycle. Insufficient seedling emergence and inappropriate stand establishment are the main constraints in the production of crops which receiving less rainfall. Farmers do not have sufficient resources to meet the requirement of seedbed preparation for sowing and they are at more risk as compared to progressive farmers. On the other hand good establishment increases competitiveness against weeds, increases tolerance to drought period, increase yield and avoids the time consuming need for re-sowing that is costly too. It is well accepted fact that priming improves germination, reduces seedling emergence time and improves stand establishment. A method to improve the rate and uniformity of germination is the priming or physiological advancement of the seed lot. To determine the effectiveness of different priming techniques, factors such as concentration, a dose of priming agent, the time period for incubation of seed in priming agent, and seed storability must be examined, and the optimal conditions should be determined.

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Digital Agriculture and the Role of AI in Farm Economics

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Introduction

In this modern era of the industrial revolution 4.0, almost all activities of human life cannot be separated from the use of information technology (IT) as an enabler for other activities and services. IT is no longer just a tool and is now a required component that must be owned. Its advancement, which significantly facilitates human life activities, has resulted in a high reliance on the existence of information technology (Rahmatullah *et al.*, 2022). In addition, since technology plays a much more significant role in the digital era than it did in previous generations, today's generation is technologically literate. The rise in literacy, combined with recent technological advancements, has resulted in expanding technology in education. These are the generations entering the classroom today, ranging from millennials to Gen-Z, and they all share distinct characteristics that define their age. These generations expect to be actively engaged in their learning and do not perform well as passive learners. As a result, technology must be embraced in today's education, and teachers must incorporate technology into their students' learning (Hashim, 2018). Rapid advances in big data and artificial intelligence technologies have profoundly impacted all aspects of

human society, including the economy, politics, science, and education. Over the past 30 years, farming practices have been influenced by the use of automation and control systems, data processing software, web-based applications, and mobile tools, all with the main goal of maximizing the efficiency of the lands and resources. Up until 2010, cultivators required to monitor their fields and spot flaws using the Global Positioning System (GPS), satellite maps, ground-based sensing platforms, and local sensing tools like data recorders. Digital agriculture (DA) and smart farming techniques moved toward digitalization with the advent of Unmanned Aerial Vehicles (UAV), low-powered long-range wireless sensors, Internet of Things (IoT) devices, and robotics (Basso and Antle, 2020). They contributed to the economic development and sustainability of food production. Indian farmers are predominantly small holder farmers (SHFs), and there are more than 40 critical farming activities that need attention and decision support to ensure good yields and returns on investment. New and emerging technologies such as the internet of things (IoT), drones, mobility, cloud computing, big data, remote sensing, artificial intelligence (AI), machine learning (ML), image analytics and processing, block chain, and agribots

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are poised to transform traditional agriculture into data-driven precision farming to generate sustainable profits (FICCI, 2022). Digital technologies can create promising business opportunities in agriculture and at this juncture, farmer has to be made a partner in the emerging business space from the start. It will not be an easy task given socio-political-economic conditions prevailing in the country.

Aims of artificial intelligence (AI)

Enhanced Efficiency and Automation: AI is designed to automate repetitive and mundane tasks, freeing up human resources to focus on more complex and creative endeavors. This leads to increased efficiency and productivity in various industries and domains.

Data Analysis and Decision-Making: AI can process and analyze vast amounts of data quickly and accurately, providing valuable insights and supporting data-driven decision making. This helps businesses and organizations make informed choices to improve processes, strategies, and outcomes.

Prediction and Forecasting: AI can predict future outcomes and trends based on historical data and patterns. This predictive capability helps in planning and strategizing for the future, whether in financial markets, weather forecasting, or customer behavior.

Personalization and Tailored Experiences: AI enables personalized experiences by understanding and adapting to individual preferences and behaviors. This applies to various aspects, such as personalized recommendations in e-commerce, content customization, and adaptive learning.

Problem-Solving and Optimization: AI can solve complex problems and optimize processes by evaluating numerous variables and finding the most efficient solutions. This is particularly useful in areas like logistics, resource allocation and manufacturing.

Natural Language Understanding and Communication: AI, especially Natural Language Processing (NLP), allows machines to comprehend, process, and generate human language. This facilitates effective communication, chatbots, language translation, and more.



Enhanced Safety and Security: AI contributes to safety by monitoring and predicting potential risks in various domains, including cybersecurity, public safety, and autonomous vehicles.

Creative and Artistic Expression: AI can generate creative content, such as music, art, and writing, showcasing the potential for collaboration between human creativity and machine intelligence.

AI Applications in Agriculture

Precision Farming: AI facilitates precision farming by analyzing data from soil sensors, weather forecasts and satellite images. This approach enables farmers to apply inputs such as water, fertilizers, and pesticides more efficiently, thereby increasing yields

while minimizing costs. Research indicates that AI-driven sowing recommendations have led to a 12 to 17 per cent increase in cotton yields (Tsoumas *et al.*, 2023).

Predictive Analytics: AI algorithms process historical weather data, soil conditions, and crop performance to forecast future trends. This helps farmers anticipate changes and plan accordingly. For instance, predictive models can forecast the best planting and harvesting times, likely pest outbreaks, and expected yield quantities.

Autonomous Machinery: Self-driving tractors and robotic harvesters, powered by AI, are streamlining agricultural operations by reducing labour requirements and improving efficiency. These machines carry out precise tasks such as planting, weeding, and harvesting, reducing waste and increasing overall productivity. However, high costs and technical complexities pose barriers to widespread adoption, particularly for small-scale farmers.

Soil Health Monitoring: AI systems analyze soil samples to determine nutrient levels and other critical parameters. This data helps in creating precise fertilization plans, reducing the use of chemical fertilizers, and enhancing soil health. AI-driven soil monitoring ensures that nutrients are applied only where and when needed, promoting sustainable farming practices.

Crop Monitoring and Disease Detection: AI-driven drones and imaging technologies provide real time monitoring of crop health, enabling early detection of diseases, pests, and nutrient deficiencies.

This allows for timely interventions, reducing losses and improving crop quality. The Agrovie platform, for instance, utilizes AI to analyze UAV-collected data, supporting precision farming strategies. (Chaterji *et al.* 2020).

Economic Implications

Cost Reduction: AI-based solutions minimize labor dependency and maximize resource usage, which dramatically lowers production costs. Farmers are able to deploy resources more efficiently because to automated technologies that perform repetitive activities with high precision. For example, by streamlining greenhouse operations, the iGrow system showed a 92.7% increase in net profit.

Yield Enhancement: AI helps farmers make wise decisions that increase crop yields by offering data-driven insights. Precision interventions and predictive analytics boost productivity, promoting both farm profitability and food security. Research on cotton farming has demonstrated that AI-driven recommendations significantly increase production.

Market Access and Supply Chain Efficiency: By connecting farmers and buyers through digital channels, AI improves market access by guaranteeing fair pricing and reducing the need for middlemen. AI also improves supply chains by controlling logistics and forecasting demand trends, which lowers post-harvest losses. Furthermore, AI is being used in environmental protection to track ecosystems and anticipate poaching, which supports sustainable farming methods.

Sustainability: Precision farming promotes sustain-

able agricultural practices by reducing the environmental impact of farming. By using AI to monitor and manage resources efficiently, farmers can decrease their reliance on chemical inputs, conserve water, and improve soil health.

Conclusion

Artificial intelligence marked its significance to help in the real-time monitoring of the data. It has been implemented in crop selection and to help the farmer in the selection of the fertilizers, diagnose disease and pest, nutrient management and crop productivity. With the help of the database which the user has gathered and specified to the system, the machine communicates among themselves to decide which crop is suitable for harvesting and marketing. Many significant methods can ensure farmers with better crops and proper field management. The use of artificial intelligence will help the farmers to achieve their goal of a better harvest by making better decisions in the field. The power of data can be used more efficiently to analyse scenarios, anticipate risk solutions and act before hunger continues as a humanitarian crisis.

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Methodologies for Identification and Purification of Bacterial Secondary Metabolites

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Introduction

The most cost-effective and biotechnological method for finding novel compounds has been the synthesis of secondary metabolites from action-bacteria. Antibiotics already produced numerous significant antimicrobial medications, including tetracycline, vancomycin, and chloramphenicol. There is a pressing medical need to create new naturally occurring antimicrobial agents with unique modes of action. An ecological niche that is heavily exploited is soil; its inhabitants generate a variety of beneficial bioactive natural compounds, such as antibiotics that are clinically significant. But the rise of infections that are resistant to drugs and several drugs. Necessitates a continuing search for new antimicrobial compounds with potent antimicrobial activity. Searching for previously unknown microbial strains is an effective approach for obtaining new bioactive substances. Therefore, it is indeed need of the hour to search for new drugs, especially antibiotics, to control the spread of antibiotic resistant pathogens. Secondary metabolites are low-molecular-weight chemicals that serve a variety of activities besides growth, such as protection against

abiotic and biotic stresses (Zahid *et al.*, 2023). Bacteria, particularly actinobacteria, have reserves of metabolic potential for drug development. Microbes generate a variety of secondary metabolites that serve a few functions, including (1) defense against antagonistic microorganisms, (2) adaptation to harsh environmental circumstances, (3) cooperative interaction and (4) signaling molecules for interaction among diverse biota (Ullah *et al.*, 2020). Microbial secondary metabolites can be classified according to their function or their biochemical origin. Secondary metabolites are classified into two groups based on their biochemistry: (1) soluble secondary metabolites: ribosomal peptides (bacteriocins), nonribosomal peptides (lipopeptide and siderophore), polyketides (antibiotics), volatile organic compounds (terpenes: geosmin, nitrogen compounds; pyrazines: antibiotics; indole: signaling molecules), volatile sulfur compounds, and (2) plant growth regulators- auxins (glucosinolate), cytokinins and jasmonic acid (alkaloids), gibberellins (GAs) and abscisic acid (ABA) (terpenes), salicylic acid (phenolics), and brassinosteroids (polyhydroxy steroids).

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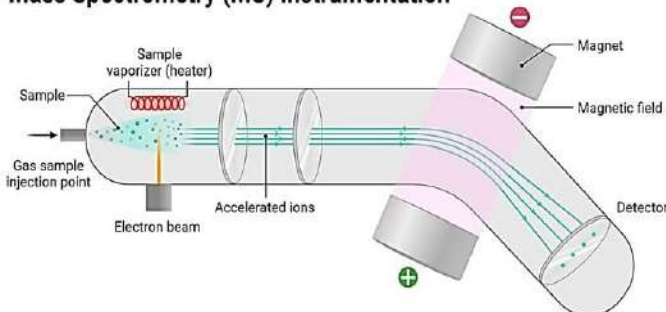
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Methodologies for identification of bacterial secondary metabolites

There are two approaches to identifying microbial secondary metabolites: targeted and untargeted. You search for a predetermined group of metabolites (about 20 metabolites) that have already been found in targeted metabolite tests. The goal of the untargeted secondary metabolites study is to find and classify a broad range of metabolites that microorganisms produce. Three main processes are used to process nontarget analytical data: (1) deconvolution, (2) alignment, and (3) gap-filling and filtering. Nuclear magnetic resonance (NMR) spectroscopy and mass spectrometry (Ms) have been important technologies in metabolomics over the past few decades.

Mass spectrometry (Ms): Ms is used to determine the mass-to-charge ratio of molecules. As chromatography works to detect the retention time of elements moving at varying speeds under certain conditions, it detects the time taken to pass by them. GC-Ms, CE-Ms, and LC-Ms are three common Ms-based analyses. Several groups of secondary metabolites, including organic acids, amino acids, sugars, lipids, etc., are easily handled by these high-throughput tools.

Mass Spectrometry (MS) Instrumentation



Nuclear magnetic resonance spectroscopy (NMR)

: The foundation of NMR spectroscopy is the use of atomic nuclei's magnetic properties to determine the physical and chemical features of the atoms or molecules they are a part of. The magnetic characteristics of the atom's isotope and the magnetic field's intensity influence the resonance frequency at which electromagnetic radiation is reemitted after being absorbed by magnetic nuclei in a magnetic field (Dunn *et al.*, 2011). Metabonomic identification can be done using both Ms and NMR. It is common to use NMR and Ms together in practice. Ms can be used to determine a molecule's formula, while NMR can be used to differentiate structural isomers. Despite Ms's greater sensitivity and ability to identify a greater number of metabolites, NMR spectroscopy is extremely quantitative and repeatable. NMR analysis, unlike Ms, demands a greater sample quantity.

Table 1: Database used for data analysis of NMR and Ms results

Nuclear magnetic resonance (NMR) spectroscopy	Mass spectrometry
METLIN (http://metlin.scripps.edu)	NIST (http://www.nist.gov/srd/nist1a.htm)
Human Metabolome Data-base (HMDB, http://www.hmdb.ca)	MassBank (http://www.massbank.jp)
Biological Magnetic Resonance Databank (http://www.bmr.bwisc.edu/metabolomics)	MMCD (http://mmcd.nmr.fam.wisc.edu)

Methodologies for purification of bacterial secondary metabolites

Secondary metabolite purification from natural sources is the most important, difficult, and time-consuming stage. The compounds are first extracted, and then different separation techniques

are used. Crude extracts, isolated straight from raw materials, are exceedingly complex and contain a low concentration of active chemicals. The right isolation and purification methods must be applied in order to produce extremely pure bioactive molecules. Future studies on secondary metabolites, including their identification, characterization, and uses, as well as the industrial manufacturing of these organic substances, require their purification. Complex secondary metabolites can also be purified by combining several purification techniques (Xiao *et al.*, 2013). The following is a synopsis of a few purification techniques and how they are used to isolate secondary metabolites from bacteria.

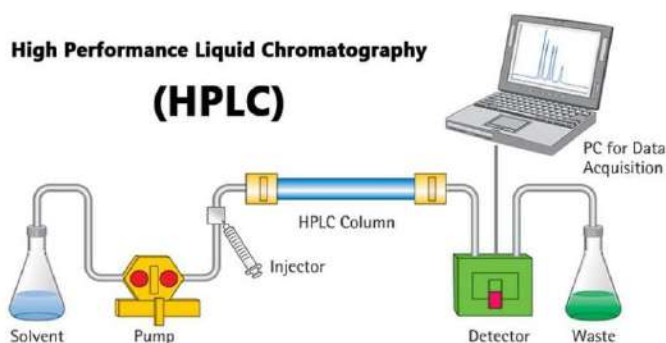
Thin-layer chromatography (TLC): Thin-layer chromatography (TLC) is a method for analyzing a mixture of solids and liquids by adsorption. This technique is useful because it is quick and requires little material. As part of TLC, a mixture is distributed between a stationary and mobile phase. On a glass plate, the adsorbent (stationary phase) is applied in a thin, uniform layer. As a result of capillary action, the organic solvent (mobile phase) moves upward and affects separation. A thin layer of adsorbent material is applied to the surface of the TLC plate, which is typically made of glass, plastic, or aluminum. The most common materials used are aluminum oxide, cellulose, and silica gel.

Column chromatography: Because of its convenience and versatility, column chromatography is the most widely used method for purifying biomolecules. The polarity of the molecules and

differential adsorption to the adsorbent are the basis for compound separation. Molecules flow through the column at varying rates depending on their polarity, which effectively separates them. The organic solvent (mobile phase) travels through a thin tube that encloses the stationary phase under pressure or gravity. As the mobile phase elutes from the column, it is collected in test tubes to purify the combination. Column chromatography is a flexible and user-friendly technique for chemical purification.

Low-pressure liquid column chromatography (LPLC):

This technique forces the mobile phase to pass through the column at low pressure. The performance of low pressure liquid column chromatography (LPLC) is primarily dependent on the particle size and the operating pressure of the packed column. As the sample components flow through the column, they get separated and reach the detector at different rates. Compounds are frequently separated from crude extracts using liquid-phase liquid chromatography.

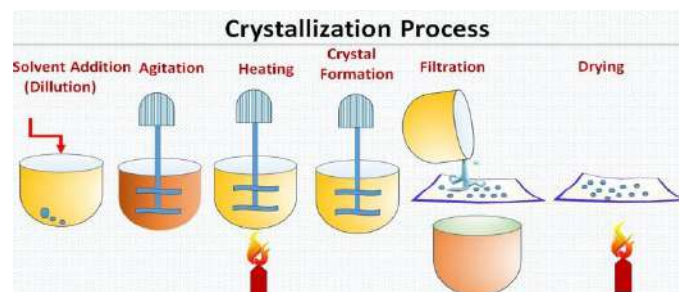


High-performance liquid chromatography (HPLC):

Separation science has increasingly embraced HPLC in recent years. Using this chromatography technique, it is possible to undertake structural and

functional analysis as well as purification of many molecules in a short period with precise results. This form of chromatography is basically a highly improved form of column chromatography in which analytes are separated by high pressure. With this technique, the mobile phases are pushed through a column containing stationary phases at high pressures (10-400 atm) and then to a detector at a constant flow rate.

Crystallization: Crystallization is a technique for separating solids from liquids. It is a process of physically transforming a liquid, solution, or gas into a solid, whose atoms or molecules are arranged in a three-dimensional crystal structure. To remove impurities from a mixture, the crystallization process must satisfy stringent structural requirements. Saturation and solubility are the two key factors in crystallization. Whenever a solid material is mixed with a liquid, the solid gets dissolved in the liquid. In addition, as more solid is added to the liquid, the solid can no longer dissolve. The stage is called a saturation point, and the fluid is called a saturated solution.



Conclusion

The development of contemporary technologies has facilitated the identification and characterization of previously undiscovered new secondary

metabolites. Due to their non-culturability or the presence of cryptic BGCs that do not express in culture medium, a number of bacterial species remain unexplored. Several of the methodologies listed above have the potential of two or more functions such as identification and characterization, such as Ms. Few approaches assess the secondary metabolites present using just the organism's genetic information. In order to obtain results, hybrid technologies combine two approaches. Thanks to developments in contemporary technologies, scientists may now discover novel secondary metabolites that have applications in both agriculture and health.

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Youth in Agriculture: Era of Green Entrepreneurship

Nirali Usadadiya, Anshika Jain and Rajat Mondal

Introduction

Agriculture is core to every nation's development and it remains fundamental to poverty reduction and economic growth especially for the developing countries in the 21st century (World Bank, 2008). Presently, Indian agriculture is facing a number of emerging challenges in spite of the production boom that it has experienced as a boon of green revolution. The concerns have shifted from production to more complicated, subtle and multifaceted issues. Some of the contemporary problems in Indian agriculture are land fragmentation, labour shortage, depleting natural resources, climate change, low profitability, competition due to market liberalization, nutrition and gender issues etc. Under such circumstances the agriculture sector needs new ideas, innovations, rebranding and revitalization to combat these prevailing challenges. The present scenario of changing agriculture in India demands the energy and vitality of youth. Provided there is enough opportunity, the innovative mind, energy and vigor of youth which is current demographic strength of the country can boost up the present status of agriculture. On the contrary, there is decreasing youth participation in agriculture over the time.

This indeed raises the question if there is scope for leveraging youth in agriculture sector to bring prosperity in the sector and as well as the lives of these young people. We live in a land of young people. This is our most valuable resource. Young people have innovative imaginations and can accomplish seemingly insurmountable tasks like managing the monsoon, mitigating and adapting to climate change, and enduring starvation. The average size of farms in our nation is decreasing. Therefore, in order to maximize the benefits of scale in both the production and post-harvest stages of farming, collaboration across groups is crucial. Any society's future rests on how well its youth perceive its ability to make decisions and fulfill the obligations of responsible adult citizenship. Young people's cooperation and involvement are essential to maximizing the benefits of the agricultural vocation. The lack of cooperation from the local head is another significant issue, according to young people living in rural areas. The majority of young people in rural areas believed that their inability to meet their families' requirements was caused by a lack of irrigation facilities. They must acquire and implement improved methods in several areas of develop-

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ment. Specialized instruction in planting, cultivating, harvesting, enhancing production techniques, and maintaining farm machinery is necessary for young people living in rural areas. Youth is a preparedness state where a motivated person prepares to take action. Young people have transformed civilizations throughout history, thus a country's ability to advance and develop largely rests on how well-trained and disciplined its kids are. The youth of the world are suffering from unemployment. Given that the majority of young people reside in rural areas, a career in agriculture can help with this issue.

Concepts of Youth

- ✓ Youth, according to the UNO, are people who are between the ages of 15 and 24.
- ✓ The African Youth Charter defines youth as anyone who are between the ages of 15 and 35. According to sociology, young people are attempting to close the gap between their dependent infancy and their independent adulthood.
- ✓ According to psychology, the youth are people who are ending an extended time of infancy.
- ✓ As per the Ministry of Human Resources Development, individuals between the ages of 15 and 35 comprise India's youth group.

Importance of Youth involvement in Agriculture

In many cases, agricultural labour migrates to urban areas because urban wage rates in even the unorganized sector are better than those prevailing in agriculture (Mehrotra *et al.*, 2013). People perceive this kind of work to be better than agriculture even if they do not provide employment security, income

security or social security. The average size of operational land holding is also declining in rural areas due to land fragmentation. The country's sustainable food security depends on increased agricultural expansion, and the need for food grains will only rise. To stay up with these varied asks that agriculture be diversified and modernized. Young individuals infuse the workforce with vibrancy, inventiveness, and energy. Many young farmers pursue high-tech, high-risk and high-return agricultural endeavors that older farmers tend to avoid, such as precision farming, organic farming, floriculture, growing medicinal and fragrant plants, protected agriculture, etc. (Bhat *et al.*, 2015). Given their increased capacity to adopt new ideas, concepts, and technology, youth could be the perfect catalyst to improve agriculture's negative reputation (Akosa, 2011). As a result, losing young people means losing the chance to modernize and compete in the current globalized world.



The involvement of youth in agricultural production is significant not only because of the need to feed the country, but most importantly because it offers options for wealth creation and financial secu-

riety. It has the potential of reducing the problems of increasing youth unemployment and this calls for securing the interest and participation of young people in agriculture by deliberate shift in policy, training and promotion that specially targets the youth. Young people will freely voice their opinions about any technology, variety, or practice that aids in better decision-making by the government and promoting institutions and allows them to adapt technologies to meet the demands of farmers.

Efforts to improve rural youth's capabilities

Nehru Yuva Kendra Sangathan (NYKS): Nehru Yuva Kendras were founded in 1972 with the intention of giving young people in rural areas a way to participate in the process of developing the nation while also giving them the chance to grow as individuals and as individuals. To supervise the operations of these Kendras, the Government of India's Ministry of Youth Affairs and Sports established the Nehru Yuva Kendra Sangathan (NYKS) as an independent body in 1987-88. NYKS is the world's largest grassroots youth organization of its sort. It uses the values of self-help, community involvement, and voluntarism to channel the potential of young people.

Agri-Clinic and Agri-business Centre: Together with NABARD, the Ministry of Agriculture and Farmers Welfare of the Government of India launched a unique effort on April 9, 2002, to implement better farming methods for all farmers across the country. The program's objective was to provide viable self-employment options to unemp-

loyed agricultural graduates, holders of agricultural diplomas, graduates of intermediate agricultural and biological science programs, and individuals with postgraduate degrees in agri-related subjects. This program's objective is to gain access to the extensive experience of agriculture graduates.

Agricultural Skill Council of India (ASCI): In January 2013, the Agriculture Skill Council of India was established as a Section 25 company under the Ministry of Company Affairs' Companies Act. Building capacity in the agriculture industry and bridging the gap between labs and farms are the goals of ASCI. ASCI aims to improve the skills of agricultural laborers, cultivators, and both direct and indirect workers involved in both organized & unorganized agriculture as well as related industries.

Entrepreneurship development: Due to India's reliance on the monsoon for agriculture, the majority of the country is monocropped. It is unable to support the farm family's way of life, which leads to young people moving to cities in pursuit of employment. Thus, fostering youth entrepreneurship through training in various agro-based businesses.

Conclusion

A sizable section of India continues to experience hunger, poverty, marginalization, and social isolation while having one of the fastest-growing economies. As the nation's largest employer, the agriculture industry has an obligation to give its workers stable and sustainable livelihoods. If the current issues facing this industry are not addressed, India would be doomed to poverty, food

insecurity, and a greater reliance on expensive imports. Unfortunately, due to the numerous obstacles that this industry currently faces, farming is no longer seen as a viable career choice for the nation's youth. Numerous sources provide evidence of the growing apathy of young people in farming. With careful alteration in the present mechanism of this sector, it can have the potential to engross the massive youth workforce presently available in the country. This would automatically contribute to resolving the crisis of youth unemployment and migration as well. In order to attract and retain youth in agriculture a respectable brand image is to be formed so that people's view on this sector is altered. Today, agriculture needs to be perceived as an enterprise and the farmer as an agri-preneur. A vast range of scopes exist in this sector which await exploration by youth as they have the desired innovativeness and creativity needed for reshaping agriculture. What is needed at present is to formulate proper policies and strategies to attract and retain youth in this sector so that Indian agriculture can experience a new stature in the hand of young and enthusiastic farmers.

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Integrated Nutrient Management for Sustainable Agriculture

Saras

Introduction

In the backdrop of demography-driven diminishing per capita availability of land (more so in fruit crops), sustaining soil fertility management has gained a phenomenal significance in meeting the multipronged challenges of sustaining the quality production on one hand and ensuring the carrying capacity of soil health on the other hand (Srivastava and Singh, 2003). Integrated nutrient supply, utilisation, or management systems (INM) include all major plant nutrition supplies must be supplied, used, or supervised in an efficient and cautious manner, including chemical fertilisers in conjunction with animal manures, compost, and green manures. Legumes in cropping systems, bio-fertilizers, crop residues or recyclable trash, and other locally accessible nutrient resources are used to improve soil fertility, health, and production. The combined supply and use of plant nutrients from chemical fertilisers and organic manures has been shown to provide larger crop yields than when each is applied separately. This increase in crop productivity results from their mutual and harmonious effect, which helps to advance the chemical, physical, and biological protagonists of soil and, as a result, the soil organic matter and nutrient standing; to a large extent well-adjusted nutrient supply to crops of cropping systems, and with no or negligible poisonous effect

on the environment, if any. Providing crops with a balanced nutrient supply that preserves and improves soil fertility health is the main objective of integrated nutrient delivery and management. For sustained high output. The applicable combination or combinations of plant nutrient sources to a production approach for an optimal and balanced nutrient supply vary depending on land use, environmental, social, and economic circumstances because these sources differ greatly in terms of nutrient substances, delivery efficiency or fascination, positional availability, crop specificity, farmer appropriateness, and so forth. Regardless of soil type or agro-ecological zone, fertilizers and manures are essential components of new technologies that support a 50-60% rise in food grain output in India. However, without a combined supply and use of plant nutrients from chemical fertilizers and organic sources, increased production is improbable. By transforming the chemical energy of fertilizers and manures into biomass with a higher grain: straw ratio, the HYV produces impressive production increases. In nations with little land, like as India, the best method for conserving land is the use of fertilizer. The Integrated Plant Nutrient System (IPNS) is a blend of organic and inorganic fertilizers that can be used to reduce the use of chemical fertilizers by establishing a balance between fertilizer inputs and crop nutrient

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requirements, thereby maintaining soil fertility, restoring soil health, and continuously providing plants with nutrient requirements. Bilkis *et al.* (2017) found that using PM and VC-based INPS techniques boosted yield, nitrogen uptake, and soil fertility in the Boro-Fallow-T. Aman Rice cropping pattern. Saha *et al.* (2010) discovered that adding NPK fertilisers, organic manure, lime, and biofertilizers increased soil organic carbon (SOC), aggregate stability, moisture retention capacity, and infiltration rate while decreasing Bulk Density.

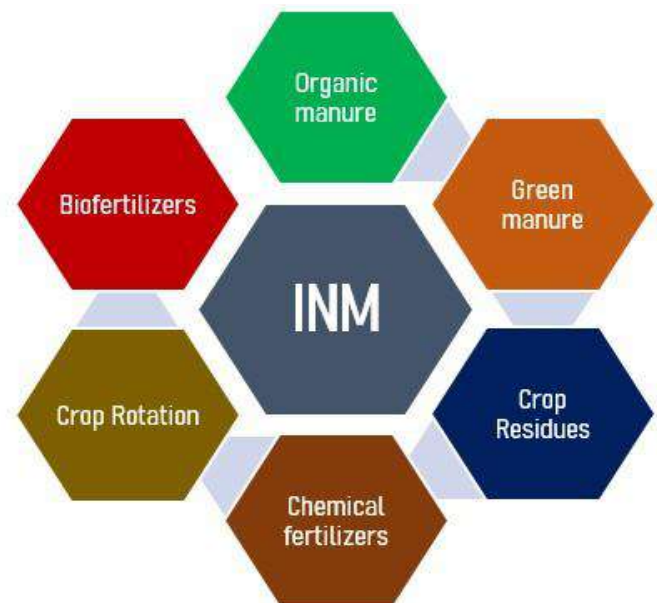
Need of Integrated Nutrient Management (INM)

- ✓ P, S, and Zn deficits occur more quickly and are linked to increased usage of N fertilizers.
- ✓ N treatment alone lowers plant growth in severely P-deficient soils.
- ✓ Soil Organic Matter decline brought on by ongoing nitrogen fertilizer application
- ✓ Constant application of fertilizers that cause acidification of the soil.
- ✓ Soil Organic Matter depletion and decreased soil fertility are caused by a shift in land use from the forest environment to the agro ecosystem. Effective nutrition management has been crucial in India in achieving the dramatic increase in food production.

Components of Integrated Nutrient Management (INM)

Integrated Nutrient Management (INM) is a comprehensive method to nutrient management in agriculture that attempts to maximize fertilizer use efficiency, improve soil fertility, and encourage

long-term crop production. It entails combining several nutrient sources and management practices to suit the crop's nutrient needs while minimizing environmental effect. The following are the essential components of Integrated Nutrient Management, along with descriptions of each:



Soil Testing and Nutrient Diagnosis: The first stage in INM is to analyse soil samples to evaluate nutrient status, pH, organic matter concentration, and other essential soil parameters. Nutrient analysis identifies specific nutrient deficits or imbalances in the soil, allowing for more focused fertilizer treatment.

Organic Manures and Crop Residues: Organic manures including farmyard manure, compost, and green manure are rich in nutrients and organic materials. They promote soil structure, nutrient availability, and moisture retention. To improve soil fertility, crop leftovers such as stalks and leaves can be mixed into the soil or used as mulch.

Chemical Fertilizers: Chemical fertilizers provide

essential nutrients to crops in forms that are readily available. INM places a strong emphasis on applying fertilizers sensibly and in balance, taking into account crop nutrient needs and soil test recommendations. Applications of fertilizer are tailored to meet particular nutrient needs, reducing nutrient waste and possible harm to the environment.

Integrated Nutrient Supply: INM emphasizes the integration of several nutrient sources, such as organic manures, chemical fertilizers, and bio fertilizers, to give crops with a balanced and diverse nutrient supply. This method ensures a complete nutrition supply that meets the crop's needs throughout the growth phases.

Bio-fertilizers: Biofertilisers are organic product containing a biologically active and efficient strain of specific microorganisms or in combination which may play an important role when used for application to seed, soil or composting area to improve soil fertility and crop productivity due to their ability to Fix atmospheric nitrogen (symbiotic and asymbiotic), Transform native soil nutrients such as phosphorus, zinc, copper, iron, sulfur etc from the non-usable (fixed) to usable form. Azotobacter is mainly used as an inoculant for vegetable crops, cotton, sugarcane, maize, sorghum, pearl millet and ornamental plants. Azotobacter can produce antibiotics and fungistic substances against pathogens like *Fusarium*, *Alternaria* and *Trichoderma* and this characteristic may prove advantageous to its action in improving health and growth of plants.

Advantages of Integrated Nutrient Management

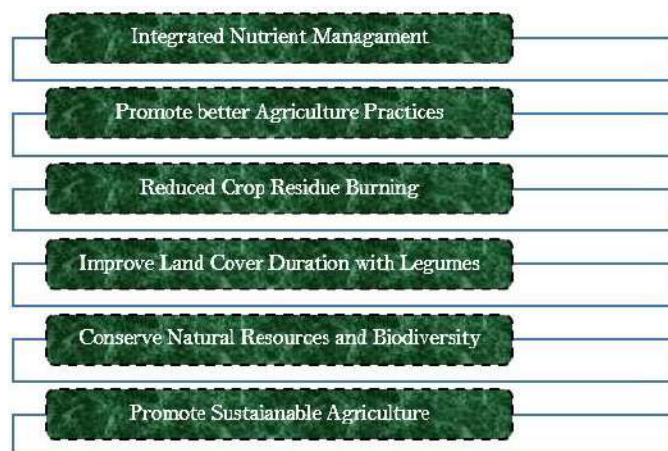


Fig. 2: Impact of Integrated Nutrient Management (INM) on better agriculture practices

Improved Nutrient Use Efficiency: INM encourages the wise and balanced use of nutrient sources such as organic manures, chemical fertilisers, and biofertilizers. INM techniques have been proven in studies to greatly enhance fertiliser use efficiency, ensuring that nutrients are supplied in the correct amounts and at the right time to meet crop demands (Kumar *et al.*, 2016; Islam *et al.*, 2019). As a result, nutrient losses are minimised, crop nutrient uptake is raised, and nutrient utilisation is optimized.

Sustainable Crop Production: INM Practices boost long-term crop performance by supplying a complete and balanced nutrient supply. INM's blend of organic and inorganic nutrient sources optimises Nutrient availability to crops at all phases of growth, promoting improved growth, development and production.

Environmental Benefits: INM aids the environment by lowering nutrient losses and the risk for water and soil pollution. Proper nutrient management based on soil testing and crop nutrient requirements reduces the need for excessive chemical fertiliser use, lower-

ing the risk of nutrient runoff and leaching. The incorporation of organic manures and biofertilizers into INM reduces reliance on synthetic fertilisers, hence contributing to more sustainable farming practices.

Economic Viability: Farmers have found INM practises to be economically viable and financially rewarding. According to research, INM techniques can lead to enhanced profitability, lower input costs, and higher returns on investment.

Conclusion

So long as agriculture continues a soil-based industry, there is no way that needed yield escalations of the major crops can be accomplished without safeguarding that plants have an satisfactory and steady supply of nutrients. The applicable environment must occur for nutrients to be accessible to a particular crop in the suitable right form, in the proper absolute and relative quantities, and at the right time for high yields to be appreciated in the short and long term. Among various improved agro techniques Integrated Nutrient Management (INM) has been proved to be the best options to augment good quality forage production per unit area by sustaining soil fertility and its productivity under limited land resources available today.

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Biological Control of Pests in Vegetable Crops

A. Sivaraman, S. Swetha and D. Sujatha

Introduction

India is one of the world's largest agricultural countries, with more than 60% of the population employed in agriculture and related activities. Agriculture in India contributes an 18.6% share of the national GDP. India produces almost all crops, including cereals, vegetables and cash crops (Vanitha *et al.*, 2013). Insect pests are the major biotic constraints to vegetables production in India. Apart from causing direct damage many of them also act as vectors for several viral diseases. The crop losses to the tune of 30-40 per cent have been reported in vegetable crops. Most of the plant protection recommendations in vegetables so far indicated the calendar-based scheduled application of insecticides and acaricides. This has become a common practice over the years by most of the farmers, growing vegetables in the country (Roy *et al.*, 2017). Establishment of new/invasive pests in India is also a matter of concern. Many such new emerging pests have occurred in India during last decade. The development of contemporary technologies has facilitated the identification and characterization of previously undiscovered new secondary metabolites. Due to their non-culturability

or the presence of cryptic Biological controls (BGCs) that do not express in culture medium, a number of bacterial species remain unexplored. Several of the methodologies listed above have the potential of two or more functions such as identification and characterization, such as Ms. Few approaches assess the secondary metabolites present using just the organism's genetic information. In order to obtain results, hybrid technologies combine two approaches. Some of the insect pests of vegetable crops become major and are gradually attaining the major pest status in different regions of the country due to changes in the ecosystem and habitats. *Helicoverpa armigera* in tomato, whitefly, *Bemisia tabaci*, serpentine leaf miner, *Liriomyza trifolii* on tomato and cucurbitaceous crops, fruit fly on fruits and vegetables, mealy bugs on several horticultural crops, gall midge on brinjal, okra stem fly and bitter gourd leafhopper, red spider mite on okra, brinjal, cowpea, Indian bean and nematodes on several vegetable crops are some of the examples. In recent times, there were outbreak of gall midge (*Asphondylia capparidis*), which known to be a minor pest and gradually becoming a regular problem in chilli, capsicum and brinjal in the states of Andhra

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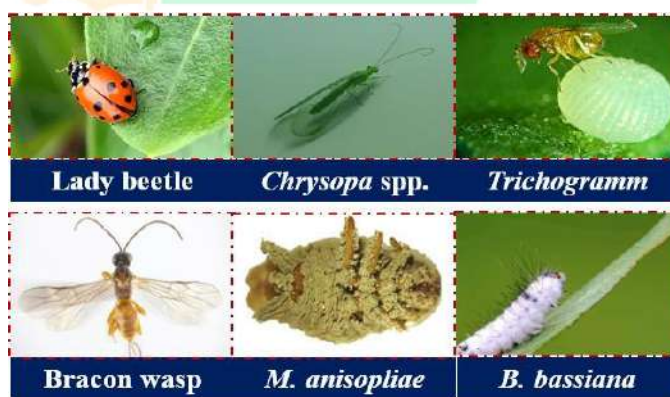
Table 1: Pest of Major Vegetable Crops and their Symptoms

Pest	Crop	Symptoms
Aphid (<i>Myzus persicae</i>)	Tomato, chilli, Potato	Curling of leaves and growth is affected.
Aphid (<i>Aphis gossypii</i>)	Okra, Tomato	Curling of leaves and stunted growth.
Whitefly (<i>Bemisia tabaci</i>)	Okra, Tomato, Brinjal, Chilli, Cucurbits crops	Infested leaves curl and dry. These insects transmit yellow vein mosaic virus in bhendi and leaf curl virus in tomato.
Mite (<i>Tetranychus</i> spp.)	Brinjal, Okra, Tomato	Yellowing and discolouration of leaves. Presence of silken webs on infested plant parts.
Thrips (<i>Thrips tabaci</i>)	Chilli, Onion, Brinjal	White to Silvery patches on emerging leaves. Vector of tomato spotted wilt virus (TOSPO virus)
Leaf miner (<i>Liriomyza trifolii</i>)	Tomato, Cucurbits	Serpentine mines into the leaf between the upper and lower surfaces and feed on the mesophyll tissues.
Brinjal shoot and fruit borer (<i>Leucinodes orbonalis</i>)	Brinjal	Boreholes in tender shoots resulting in drooping or drying of tips. In fruits, boreholes are plugged with excreta.
Fruit borer (<i>Helicoverpa armigera</i>)	Tomato, Bhendi, chilli	Caterpillars bore the fruit and feed on the pulp.
Oriental leafworm moth (<i>Spodoptera litura</i>)	Tomato, chilli, Cabbage	Caterpillars skeletonize the leaves. They scrape the green matter in the leaf leaving the epidermis alone.
Shoot and fruit borer (<i>Earias vittella</i>)	Okra	Caterpillars bore into the terminal tender shoots that lead to withering and drooping down of growing tips. Boreholes in the fruits and infested fruits are unfit for marketing.

Pradesh and Karnataka and in brinjal in Chattisgarh. Various species of mealy bugs in cotton, vegetables and papaya have intensified their severity of occurrence in different parts of the country and have become indicator insects for the current ecosystems due to slow changes in climate in the last one decade. Thanks to developments in contemporary technologies, scientists may now discover novel secondary metabolites that have applications in both agriculture and health. Although there are many different methods for managing pests, chemical pesticides are the most widely employed, especially in the years after the green revolution. However, the extensive and uncontrolled use of chemical pesticides has led to a number of problems, such as chemical residues in final products, detrimental effects on the health of people and animals, and negative environmental effects. On the other hand, a number of studies show that most insect pests have developed resistance to widely used pesticides. Pests

are also making a comeback in several sections of the country. To achieve sustainable crop protection, production, and environmental safety, researchers and farmers have been looking for alternative or corrective pest management techniques.

Management of insect and mite pests using biological control agents



Different Biocontrol Agents

In India, the majority of plant protection measures are entirely reliant on chemical pesticides. Farmers apply pesticides on a calendar-based schedule. Given the high value of vegetable crops, even a little infestation can result in a loss of quality

and reduced yields. As a result, farmers are regularly spraying pesticides, even if the chemical is below the ETL. This has become into a routine activity for vegetable growers throughout the years. Without being observed, natural flora and animals are being harmed, as well as economically valuable insects such as predators, parasitoids and bees. Farmers must therefore utilize organic management measures to save these beneficial insects while also protecting the environment (Halder *et al.*, 2011).

Predators: Beneficial insects and other vertebrates that seek and eat pests directly are known as predators. General predatory insects include ladybugs (also known as ladybird beetles), preying mantids, green lacewings, carabid beetles, rove beetles, hoverflies, minute pirate bugs, mirid bugs, big-eyed bugs, arachnids like spiders, and predatory mites. Since the majority of ladybird species prey on pests like Homoptera and Acarina, they are seen as beneficial. These predatory ladybirds help to regulate the populations of their prey and, in some cases, provide a high amount of control. People may benefit when ladybirds naturally offer a high degree of pest management or when combined with other predators, parasitoids and diseases to provide a significant amount of pest population management. That is, gardeners, growers and farmers may benefit for free as they have no or little pest concerns. The adults and larvae of ladybug beetles consume a variety of tiny, soft-bodied insects, as well as their eggs and larvae.

Parasitoids: Living things called parasitoids reside on or within their hosts and consume them.

Both within and outside of an insect's body, these parasites can flourish. Only the insect host's immature stage is consumed by the parasites. Numerous parasites' adult females feed on and serve as a basic biological control source for their hosts, such as the numerous hymenopteran wasps that feed on scale insects and whiteflies (Sanda and Sunusi, 2014). Diptera (flies) and Hymenoptera (wasps) account for the vast majority of parasitic insects. More than a dozen Hymenoptera families contain wasps that are parasitic on other wasps. Aphidiinae (a subfamily of Braconidae) are aphid predators that feed on aphids, which are a pest in many crops. Trichogrammatidae is another family that parasitizes eggs. *Aphelinidae*, *Encyrtidae*, *Eulophidae* and *Ichneumonidae* are some of the other parasitoid families. In India, 37 parasitoid species have been discovered on *Helicoverpa armigera*, although only eight are deemed significant. According to Alam *et al.* (2006), the regular introduction of the egg parasitoid *Trichogramma chilonis* Ishii at a rate of 1 g of parasitized eggs ha⁻¹ week⁻¹, along with the larval parasitoid *Bracon hebetor*. The population density of 800-1000 adults ha⁻¹ week⁻¹, has proven to be an effective method for lowering the population of the Brinjal Shoot and Fruit Borer. According to Cork *et al.* (2003), the installation of Brinjal Shoot and Fruit Borer sex pheromone lures in traps has been found to effectively mitigate fruit damage and enhance yield, with a recommended density of 100 traps per hectare.

Fungus: Various entomopathogenic fungi employed

in management of the various pest in vegetable crops. *Metarhizium anisopliae* has the potential to be an extremely beneficial pathogen for insect pests and is currently being studied for myco-biocontrol of a number of well-known insect pests. In a variety of horticultural growing media (Peat, coir, bark and peat blends with 10% and 20% composted green waste), the entomogenous fungus *Metarhizium anisopliae* V275 was more effective at killing western flower thrips pupae than chemical insecticides (imidacloprid, fipronil) (70-90% versus 20-50%). By including *M. anisopliae* in the growing media, drench treatments in coir and peat mixtures containing 20% composted green waste, insect pests were controlled more effectively. The microbial control agents *Bacillus thuringiensis*, *Beauveria bassiana* and *Metarhizium anisopliae* have been tested by Sabbour (2015) against the tomato pinworm *Tuta absoluta* under laboratory and greenhouse conditions. The results showed that these agents were effective in reducing infestation and mortality rates of *T. absoluta*, with *M. anisopliae* showing the highest percentage of parasitism after treatments. A combination of mass release of *Trichogramma pertiosum* and *B. thuringiensis* resulted in only 2% fruit damage in South America. Aphids, thrips, grasshoppers and certain beetles are all susceptible to white muscadine disease, which is caused by the entomopathogenic bacteria *Beauveria bassiana*. Unlike *Nosema locustae*, it does not require the host to consume the spores; instead, *B. bassiana* spores simply contact a host

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Glaucanite: An Alternative Potash Source for Sustainable Agriculture

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Abstract

Potassium (K) is essential primary macronutrient. It has an important role in crop productivity as well as ensuring food security, quality of agricultural produce and further contributes to economic viability, improved ecological conditions and long-term agricultural sustainability. Potassium is traditionally supplied through conventional potassium fertilizers such as potassium chloride (MOP) and the entire requirements of potassic fertilizers is fulfilled through imports from foreign country. However, concerns regarding the sustainability, cost and environmental impact of conventional potash mining have led to the exploration of indigenous alternative sources such as glauconite which is a potassium-rich silicate mineral and has emerged as a promising potash source due to its natural abundance and slow-release properties. Glaucanite is a natural, abundant mineral rich in K and can be used as a K fertilizer source for benefiting the agriculture. India has the largest deposition of a glauconitic sandstone which could offer a cheap and locally derived source of slow-releasing K fertilizer. Usage of glauconite in farming practices replaces K fertilizers, offering benefits from both economic and environmental perspectives, supply additional nutrients along with K, nourishes soil health and helps in achieving sustainability in agro-ecosystem.

Introduction

Now-a-days, worldwide concern mainly about food, nutritional security and the population continues to increase, the demand for food crops is steadily increasing. Potassium (K) is essential primary macro-nutrient. It is helpful for growth and reproduction of plants which maintains balance between nitrogen and phosphorus in plants like traff-

ic policeman. It is essential for important biochemical processes in plants (Zorb *et al.*, 2014). Potassium fertilizers play a crucial role in achieving self-sufficiency in food grain production. Soil contains rich reserves of K, among which only 1-2 per cent can be directly accessible by plants. Increasing area under K deficiency, there is urgent need to increase potassium usage from the current 17 to 30 kg K₂O

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ha⁻¹ to ensure sustainable food production in future. However, in India, there is no commercial production of indigenous potassium resources for fertilizer purpose. Currently, the K demand is satisfied by mineral salts of high potassium concentrations and the complete requirements of potassic fertilizers are fully reliant on imports (Shirale *et al.*, 2018). Discovering of indigenous alternative source of potassium can helps in saving import cost of fertilizers from other countries and reduce extra burden of subsidy providing by government for potassic fertilizer.

Mostly potassium minerals are found in insoluble forms in rocks like feldspar (orthoclase) and mica (muscovite and biotite) and it is not radially available for the plants. In world, concentrated potash minerals such as sylvinite (KCl + NaCl mixtures), sylvite (only KCl), carnallite and kainite in soluble forms that are ideal salt for use of production of potassium fertilizers but the limited occurrences of high-grade salt deposits and the rising demand for potassium fertilizers, glauconite mineral can be considered a potential source of potash for production of K fertilizers in future. Glauconite is iron-potassium phyllosilicate silicate mineral and member of mica family. Glauconite sandstone is used directly as fertilizer or it can be used as concentrated potassium fertilizers sources after beneficiation process. It has been playing a crucial role in improving and maintaining long term soil fertility apart from potassium chloride salt which have a certain ill effect like the chloride toxicity in

soils. Also, it does not contain any toxic element above the permissible limits and serves as a best source of potash for the improvement of soil health (Prakash and Verma, 2018).



Deposits of glauconite (a), Glauconite granules (b) and Glauconite rock(c)

Depositions of Glauconite Mineral

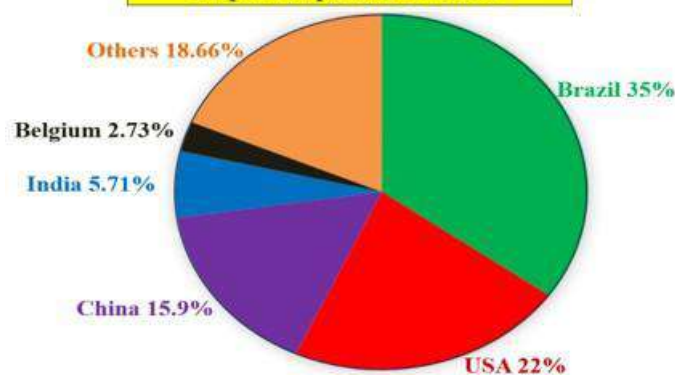
Glauconitic sandstone is mostly found in many countries like Russia, Belgium, India North America and Australia. India is having deposits of 3149 million tonnes of glauconite and Rajasthan alone contributes 94 per cent resources followed by Madhya Pradesh (5%) and Uttar Pradesh, Gujrat, Bihar, Himachal Pradesh. Glauconite is almost exclusively found in peloidal forms, in sediments, sandstones, shale, marl, carbonates and marine evaporite deposits with a green oval appearance. Glauconitic rich sandstones are found in Son Valley region of Uttar Pradesh and Madhya Pradesh represent oldest glauconite deposits. In this regions glauconite ore having 10% K content (Anonymous, 2024).

Indian soils and future demand for potassic fertilizers

Today, potassium is an expensive nutrient in

India, because its supply totally depends on import from other countries. India ranks fourth in import of potassium fertilizers and consumes nearly 6% of global usage. In India, on an average 3.10 million tonnes of potassium are being imported annually from foreign countries (Anonymous, 2023).

Import of potash fertilizer

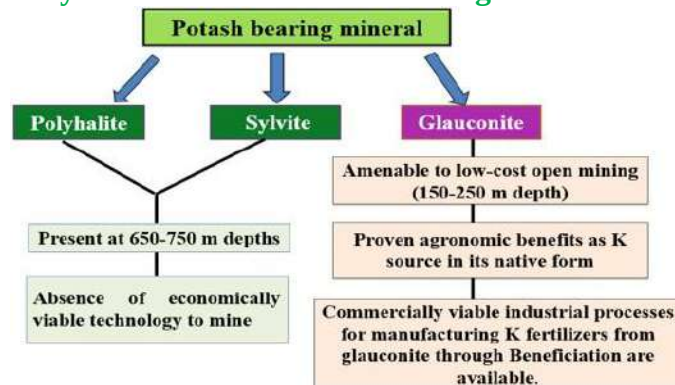


Fertilizer	Production (India's rank in world.	Consumption (India's rank in the world
Nitrogen	2 nd	2 nd
Phosphorus	2 nd	2 nd
Potassium	*	4 th

India has 4th rank in consumption and import of potash fertilizers. It has no commercially viable potash supplies because there is practically no production of potash fertilizers in the country. In this situation, Indian agriculture fully reliant on import of potassic fertilizers. Implication of import of potash fertilizer:

- ✓ Overdependence on potassic fertilizer will cause supply chain disruptions, leading to increase prices and adversely affecting farmers.
- ✓ Long-term imports decrease the nation's foreign exchange reserves by import costs and providing Govt. Subsidy (Rakesh *et al.*, 2020). To reduce the implication and dependence on imported potash, there is need to explore indigenous alternative source of potash.

Why alternative source should be glauconite



To reduce the dependence on imported potash, glauconite - a potash mineral, has been identified as an alternative source of potash. Glauconite is found at near the lithosphere and amenable to low-cost open quarrying as compare to other potash bearing minerals like polyhalite and sylvite found in India. Glauconite has ability to additionally work as soil ameliorant, best for direct application than other potash minerals (Anonymous, 2002)

Properties of glauconite

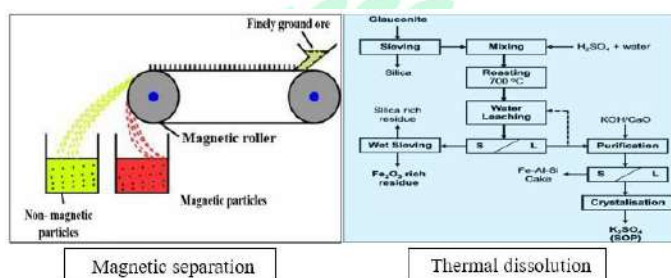
Glauconite is an iron-potassium phyllosilicate belong mica group and contains 4-8% of K_2O . It contains Fe, Mg, Al, Si and some are also rich in Ca and P.

- ✓ Its cation exchange capacity ranges from 20 to 30 $cmol(p^+) kg^{-1}$.
- ✓ Glauconite exists in green sand sized particles (0.02 to 0.05 mm) as compare to clay minerals.
- ✓ Despite heavy mass, glauconite does not behave like sand because its structure is filled with micro-pores.
- ✓ Its non-expandable nature lacks interlayer adsorption sites hence weather faster than feldspar.

- ✓ It has complex physical and chemical features; it qualifies both as a fertilizer and a soil conditioner.

Extraction of potash from glauconite

Potash is extracted from glauconite by beneficiation process. It is the process that removes the commercially valueless materials (gangue minerals) from glauconite sandstone ore to synthesize a high grade or concentrated nutrient source. It involves various techniques such as magnetic separation and thermal dissolution.



Role of glauconite in sustainable agriculture

Glauconitic can release potassium slowly and gently, it can be considered as an alternative sustainable source of soil-soluble potassium for long time and reduces the demand for costly potassium fertilizers because;

- ✓ Glauconite fertilizer supplies potassium along with phosphorous and other micronutrients such as iron, magnesium, calcium, manganese, copper and nickel up to a certain limit.
- ✓ It saves plant roots from injury that is associated with concentrated and fast acting water-soluble potassium fertilizer.
- ✓ It reduces leaching losses of potassium and groundwater pollution.
- ✓ The slow and steady release potassium pattern

matches very well with potassium-loving perennial crops.

- ✓ It improves physical and chemical properties of soils and also stimulate soil biological properties and helps in increasing efficient use of other nutrients.
- ✓ It plays a sustainable role in maintaining fertility of soil apart from potash salt which has a certain ill effect like the increase toxicity of chloride in soils. It does not contain any toxic element above the limits.
- ✓ Its high cation exchange and adsorption capacity makes glauconite appealing not only as a source of potassium but also as a soil conditioner for agricultural systems.

Conclusion

Glauconite can be considered as a sustainable source of potash for supplying potassium to crops and reduces the demand for costly potassium fertilizers. Glauconite is a slow-release, eco-friendly alternative to conventional potash fertilizers, aligning with sustainable agriculture goals and global food security initiatives. Moreover, economic analysis showed that glauconite-based fertilizers reduced input costs for farmers while maintaining sustainable agricultural production. In order to minimize the dependence on imported potassium fertilizers, glauconite a potassium rich mineral can be indigenous alternative source of potassium.

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The Importance of DUS Testing in Vegetable Seed Certification and Intellectual Property Protection

Priyanka Kumari Meena and Manish Kumar Shrivastava

Introduction

In modern vegetable farming, success depends on two crucial factors: access to quality seeds and protection of innovation. This is where seed certification and intellectual property rights (IPR) come into play. Seed certification assures farmers that they are receiving genetically pure, true-to-type, and reliable seeds. IPR safeguards breeders' innovations by granting them exclusive rights over their new varieties. At the heart of both systems lies a vital process: DUS testing which stands for Distinctness, Uniformity and Stability.

Far from being a bureaucratic formality, DUS testing is a scientific process that verifies whether a new variety is unique, consistently expressed, and genetically stable over time. In vegetable crops, even subtle differences in traits can significantly impact yield, quality, and market value. For example:

Tomato: Lycopene-rich varieties like Arka Rakshak are highly valued by health-conscious consumers and the processing industry.

Brinjal: Varieties like Arka Kusumakar, with broad leaves and long styles, show improved fruit setting and yield.

Chili: Extremely pungent types like Bhut Jolokia are prized in the spice trade.

Okra: Straight, tender pods and attractive stems, as

seen in Arka Anamika, are favored in both local and export markets.

DUS testing verifies and protects these traits, making it indispensable for breeders, seed companies and farmers alike.

What is DUS Testing?

Definition: DUS testing is the process used to evaluate whether a new plant variety is:

- ✓ **Distinct:** Clearly different from all known varieties.
- ✓ **Uniform:** Consistent in its traits across all individual plants.
- ✓ **Stable:** Maintains its traits across successive generations and growing environments.

Objectives of DUS Testing

Confirm varietal identity: Verifies that a variety is exactly what it claims to be.

Support seed certification: Ensures only stable, uniform, and distinct varieties are approved.

Enable breeder protection: Serves as a legal prerequisite for granting Plant Breeders' Rights (PBR).

Prevent duplication and fraud: Confirms that the variety is original and not a duplicate.

Build trust in the seed market: Farmers can depend on DUS-tested seeds for reliable performance.

Core Components Explained

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Distinctness: The variety must exhibit at least one clearly distinguishable trait (Example: An okra variety with red pods or a tomato with unique ridge patterns).

Uniformity: Trait expression must be consistent across all plants (Example: A chili variety showing uniform pungency and fruit shape).

Stability: Traits must remain consistent over years and across different locations (Example: A brinjal variety consistently producing elongated fruits).

Role of DUS Testing in Vegetable Seed Certification

Ensures varietal purity: DUS confirms that seeds match their genetic description.

Supports seed quality assurance: Companies use DUS to validate and maintain genetic consistency.

Essential for hybrid maintenance: In hybrids like Pusa Hybrid-2, DUS helps track traits such as fruit size and leaf shape in parental lines.

Builds farmer trust: Predictable seed performance ensures loyalty to certified suppliers.

Prevents counterfeit seeds: DUS-registered varieties are harder to imitate, reducing market fraud.

Supports trait-based pricing: High-value traits like lycopene content or purple pigmentation become easier to market with DUS verification.

Importance of DUS Testing in Intellectual Property Rights (IPR)

Core to Plant Breeders' Rights (PBR): DUS testing is mandatory for legal protection of varieties.

Acknowledges innovation: Breeders receive formal recognition for their efforts.

Enables licensing and royalties: Registered varieties can be licensed to companies, generating income for breeders.

Encourages breeding investment: Assured IP protection motivates public and private sector R&D.

Protects brand identity: DUS registration prevents unauthorized use of variety names and reputations.

Promotes niche breeding: Specialized traits can be legally protected and marketed.

Facilitates international trade: With DUS-tested varieties aligned to UPOV standards, global marketing becomes smoother.

Strengthens breeder-farmer collaboration: Breeders can form strategic partnerships with farmers through protected varieties.

Ensures reward for trait innovation: Distinctive qualities like pest resistance or high nutrition get recognized and rewarded through protection.

Challenges in DUS Testing for Vegetables

High trait diversity: Wide natural variation in crops like tomato or brinjal makes establishing distinctness challenging.

Environmental influence: Soil, water, and climate impact trait expression, complicating results.

Similar-looking varieties: Close resemblance between varieties often requires molecular tools for precise differentiation.

Seasonal limitations: Certain crops grow only in specific seasons, delaying testing.

Lack of global standards: Variations in trait definitions and testing protocols between countries create inconsistencies.

Resource-intensive: Requires land, skilled personnel, and multiple crop seasons, increasing costs.

Limited comparator access: Difficulty accessing all existing varieties hampers proper distinctness evaluation.

Cost barrier for small breeders: Formal DUS registration can be prohibitively expensive for independent developers.

Case Studies of Real Varieties

Tomato - Arka Abha (BWR-1): High-lycopene and wilt-resistant. DUS testing confirmed its red fruit color and firmness, leading to widespread adoption.

Brinjal - Arka Shirish: Long purple fruits with lobed leaves. DUS validation boosted its use in organic farming.

Chili - Pusa Jwala: Thin, spicy fruits. DUS confirmed its consistent pungency, supporting its dominance in the chili powder industry.

Okra - Arka Anamika: Long, smooth pods with distinct stem color. DUS validation helped establish its reputation in export markets.

Advantages of DUS Testing for Farmers and Breeders

For Farmers

Assured Seed Quality: Farmers receive true-to-type seeds that match promised traits like size, color, taste, and yield.

Higher Market Value: Uniform and attractive produce earns better prices in local and export markets.

Risk Reduction: Using genetically stable seeds reduces the risk of crop failure.

Access to Innovative Traits: Traits like pest resistance, drought tolerance, and higher nutrition become available through properly registered varieties.

Seed Authenticity Verification: Farmers can check official DUS registrations to verify seed authenticity.

For Breeders

Legal Recognition of Innovation: DUS testing formally proves originality and distinctness of developed varieties.

Protection against Duplication: Unauthorized multiplication and sale of their variety are prohibited.

Foundation for Royalty Earnings: Registered varieties can be licensed for profit.

Encouragement for Continued Research: Assured protection motivates investment in future breeding programs.

Global Opportunities: DUS-tested varieties can be more easily registered and marketed internationally under UPOV guidelines.

How Farmers and Companies Protect New Varieties

If a farmer develops a new vegetable variety say, a tomato line naturally resistant to drought they can seek protection under the Protection of Plant Varieties and Farmers' Rights Act, India by:

Submitting an application with complete details and supporting evidence of distinctness, uniformity, and stability (DUS test report). Proving that the variety is new, distinct, uniform, and stable according to DUS criteria. Once approved the farmer gets a Plant Breeder's Right (PBR), allowing them

control over production, sale, and licensing of their variety. Similarly, when a seed company develops a new variety such as a high-yielding hybrid brinjal it must:

- ✓ Conduct DUS testing through an accredited authority.
- ✓ File for variety registration with complete DUS proof.
- ✓ Once granted PBR protection, the company can market the variety exclusively, license it, or take legal action against unauthorized multiplication.

Regulatory Bodies Overseeing DUS Testing

India: The Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA) oversees DUS testing and variety registration.

Internationally: The International Union for the Protection of New Varieties of Plants (UPOV) establishes harmonized DUS testing guidelines for member countries.

Impact on Breeders, Farmers, and Researchers

Impact on Breeders

Formal Protection: Breeders get exclusive rights over their developed varieties.

Economic Benefits: Licensing and royalty generation become possible.

Motivation for Innovation: Encouragement for creating new, better varieties.

Impact on Farmers

Access to Better Seeds: Farmers get reliable, high-performing seeds.

Enhanced Income: Higher quality produce fetches better market prices.

Protection of Indigenous Varieties: Farmers can register and protect traditional varieties.

Impact on Researchers

Structured Evaluation: DUS testing provides a scientific base for varietal comparisons.

Data Generation: Rich datasets on traits help researchers in further breeding programs.

Collaboration Opportunities: Research institutions and private companies collaborate more actively for developing new varieties.

Conclusion

DUS testing is more than just a regulatory requirement it is the foundation of trust, innovation, and fairness in the vegetable seed industry.

Current Significance

- ✓ Rising demand for nutrient-rich, climate-resilient vegetables.
- ✓ Farmers seeking seeds that are reliable, certified, and profitable.

Future Outlook

- ✓ Molecular tools and digital phenotyping will accelerate and refine DUS evaluations.
- ✓ AI-powered platforms will improve accuracy in trait analysis and reduce human error.
- ✓ Global harmonization through UPOV standards will strengthen international trade.
- ✓ Mobile apps may soon allow farmers to verify seed authenticity through DUS databases.

As agriculture advances, DUS testing will remain a pillar of seed innovation, empowering breeders, farmers, and companies to thrive in a competitive and evolving marketplace.

Processing and Storage of Onion

Udaysinh B. Jadav and Y. A. Viradiya

Introduction

Processing: Field-received seed lots often contain high moisture levels, weed seeds, damaged seeds, off-size seeds, and other impurities. Seed processing is essential to reduce moisture to safe levels, remove unwanted materials, and eliminate damaged or deteriorated seeds. The process also involves size grading and seed treatment to enhance seed quality. In India, “seed processing” encompasses all steps required to prepare harvested seeds for marketing, including cleaning, grading, treatment and packaging.

Purpose of seed storage: The purpose of seed storage is to maintain the seed in good physical and physiological condition from the time they are harvested until the time they are planted.

Stages of seed storage: From the time the seeds attain physiological maturity until they germinate or are discarded because they are dead or otherwise worthless, they are regarded as being in storage. Conveniently, the whole storage duration can be divided into following. Storage on plants (physiological maturity until harvest), Harvest, until processed and stored in a warehouse, in storages (warehouses), in transit (rail wagons, trunks, carts, railway sheds, etc.), In retail stores, On the user's

farm. The seed quality, *i.e.* if good seed storage practices are not followed and the seeds are not treated correctly, germination and vigor may be significantly impacted at any of the stages mentioned above.

Processing of Onion: Typically, a knife is used to cut onion bulbs into the appropriate shapes and sizes. Onions can also be chopped with a variety of commercial equipment. Onions are sometimes used with other ingredients to provide the desired flavor in food preparations.

Post-Production Operations

Pre-harvest Operations: Onion leaf condition is a reliable measure of the bulb's overall health and maturity. Before harvesting, bulb onions that are to be preserved should be allowed to reach full maturity, which is when the leaves bend slightly over the bulb's top and topple over. As a practical guideline, farmers should count the number of bulbs that have fallen over in a field. The entire crop should be harvested when the percentage of overturned bulbs reaches roughly 70-80%. Harvesting could start sooner if 50-80% of the tops have fallen off. Before the onion can be seen through the split peels. Generally speaking, storage losses at optimal maturity are less than those harvested prior to top

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collapse. Bulbs typically reach maturity 100-140 days after seeding, depending on the weather and variety. After 35 to 45 days of seeding, spring onions are ready for harvest. After harvesting, the crop should be left in the sun for a few days to dry, cure, and ripen.

Harvesting & Transport: In underdeveloped nations, manual harvesting is common, where bulbs are hand-pulled after loosening with a fork. Mechanical harvesting is more prevalent in developed countries, particularly on large farms. One-phase harvesting, often using modified potato harvesters, is quicker and involves sieving, hand-grading, and loading immediately after mowing. However, two-phase harvesting is 30% to 100% more labor-intensive and expensive due to additional steps.

Curing & Drying: Before the bulb is stored, excess moisture is removed from its outer layers by both curing and drying. The primary edible tissue is kept fresh by the dried skin's surface barrier against microbial infection and water loss. Drying also reduces shrinkage during subsequent handling, reduces the occurrence of sprouting, and allows the crop to ripen before fresh consumption or long-term storage (Opara and Geyer, 1999). Drying reduces bulb weight and since they are sold mostly on a weight basis, achieving the desired level of dehydration is critical. Weight losses of 3-5% are normal under ambient drying conditions and up to 10 % with artificial drying.

Cleaning: It is crucial to be free of any impurities

that could significantly change the appearance or quality of the food. Produce that is severely damaged must be thrown out, and soil and other foreign objects must be cleared away. Unwanted items on the bulb surface can be physically removed or cleaned with air. During these procedures, care should be taken to prevent the bulb from suffering any physical harm.

Packaging

General Information: Onion packaging needs to be strong enough to hold the weight of onions during storage and transportation, allow for adequate ventilation for the air surrounding the bulbs to keep relative humidity within the required range, and, in many cases, offer a way to display information that is both legally required and commercially necessary (Brice *et al.*, 1999). Onions are often stored in loose bulk form, where bulbs settle naturally without containers, maximizing space usage and allowing better airflow than bagged or boxed storage. However, this method requires reinforced walls and retagging before marketing, and it makes regular inspection more difficult. It is suitable for large-scale operations with forced ventilation but not ideal for soft, sweet varieties like 'Vidalia Sweets' due to their susceptibility to compression damage. Alternatively, onions can be stored and transported in various containers such as boxes, cartons, bags, bins, and pre-packs, typically in 25 kg or larger quantities.

Onion Bags: Sacks and nets used for onion packaging fall into three groups: (i) general-purpose jute sacks, as used for many agricultural commoditi-

es, (ii) open-weave sacks of sisal-like fibre, (iii) open-mesh nets, normally of plastic materials and (iv) big bags, used alternatively to crates, containing up to 1000 kg. Jute sacks are readily available in most developing countries, but their disadvantages include: (i) generally too large - may contain 100 kg onions, hence difficult to handle and an increased risk of mechanical damage; (ii) bulbs are not visible through the fabric, and it is difficult to monitor condition during storage; (iii) there is some resistance to airflow if they are used in an aerated store; (iv) difficult to label effectively; and (v) recycled sacks may encourage spread of postharvest diseases.

Rigid Packages: A range of rigid containers is used to package onions for transportation, marketing, and/or storage (Opara and Geyer, 1999). The principal rigid containers are trays (10-15 kg of onions each), boxes (up to 25 kg), and bulk bins (up to 1000 kg). These types of packaging enable segregation of onions into different cultivars or sources. The choice of packaging material is crucial in onion storage. While rigid containers like wooden bins offer easier store design and better inspection, they are costly, require maintenance, and are prone to termite damage and weathering. Handling damage during filling and emptying can be high, but is reduced during loading/unloading compared to loose bulk storage.

Onion Pre-packs: Onions are commonly sold in retail outlets in pre-packs with a capacity of 0.5-1.5 kg. Pre-packing offers the following advantages over

single bulbs in heaps or bags: (i) price can be attached to produce, (ii) the collation of a number of pieces into one unit of sale may promote sale of a larger quantity than would be purchased otherwise, (iii) provides a clean odourless unit for the customer to handle, and (iv) reduces time spent at the check-out. The use of weight/price labeling machines and bar-coding has reduced the need to pack to fixed nominal weights. During preparation for retail, the quantity of produce is measured by hand or machine and filled into the pack.

Bulk Storage

General Requirements: The main goals of onion storage are to extend availability, maintain bulb quality, and minimize losses from physical, physiological, and pathological causes. Only firm, dry-necked, and cultivar-typical bulbs should be stored; thick-necked or damaged ones must be discarded. Proper cleaning, grading, and gentle handling before storage are essential. Storage conditions temperature, humidity, and atmospheric composition greatly influence storage duration and quality. Several storage methods are available, including low-temperature, high-temperature, direct harvest, and controlled atmosphere (CA) systems, each with specific recommended conditions.

Storage at Low Temperature: Successful low-temperature onion storage requires good ventilation, 70-75% relative humidity, and a consistent temperature around 0°C. Bulbs must be fully mature and dried with tight necks before storage. High airflow during the first week helps dry outer skins and bruise-

es. Excess humidity causes rooting and rot, while high temperatures lead to sprouting and disease. Spring onions need 0°C and 95% RH but store only for up to 3 weeks. Monitoring and control of conditions are essential to prevent quality loss.

Table 1: Recommended refrigerated storage conditions for spring (green) onion

Temperature (°C)	Relative humidity (%)	Length of storage
0	95-98	-
0	90-95	a few days
0	90-95	2 weeks
0	95-100	-

Table 2: Recommended refrigerated storage conditions for onion bulb

Temperature (°C)	Relative humidity (%)	Length of storage
-3-0	70-75	6 months
-3	85-90	5-7 months
-2	75-85	300 days
(-2) - (-0.6)	75-80	6 months&
-1-0	70-80	6-8 months
-0.6	78-81	6-7 months
0	75-85	6 months
0	65-75	-
0	70-75	20-24 weeks*
0	70-75	-
0	65-70	1-2 months#
0	65-70	6-8 months†
0	-	230 days
0	70-75 or 90-95	up to 120 days
0	80-85	30-35 weeks§
1-2	80-85	30-35 weeks¥
1	87	-
1.1	70-75	16-20 weeks‡
4	-	170 days
8	-	120 days

*= With 16.3% loss (red onion); #= Bermuda cultivar; †= Globe cultivar; ‡= With 14.2% loss (red onion); &= Superba cultivar; §= Optimum storage conditions, 7% maximum water loss before becoming unsaleable; ¥= Probable practical storage conditions, 7-10 days shelf-life (approx.) at 20°C after storage, 7% maximum water loss before becoming unsaleable. Compiled from (Thompson, 1996; Thompson, 1982)

Direct Harvest' Storage: The 'direct harvest system' was developed to address challenges in curing onions under unpredictable weather, and has been widely

adopted in the UK since the 1980s. In this method, green onions are harvested, topped, and immediately stored, where they are dried and cured using a controlled ventilation system. Stage I involves rapid removal of surface moisture using high airflow, regardless of relative humidity, while Stage II completes the curing process by drying the skins. Precise control of storage conditions at each stage is essential to maintaining bulb quality during long-term cold storage.

CA Storage of Onions: Controlled Atmosphere (CA) storage combined with cold storage can extend the shelf life of onions by reducing sprouting and root growth, particularly under conditions of 0-5% CO₂, 1-3% O₂, and low temperatures. Spring onions tolerate higher CO₂ and O₂ levels than bulb onions, and optimal gas compositions vary with storage temperature and cultivar. While CA storage can maintain up to 99% marketable quality after 7 months at 1°C with 5% CO₂ and 3% O₂, a 9% weight loss may occur. Effectiveness is inconsistent and cultivar-dependent, so local trials are recommended. CA storage also increases pungency in some varieties. For 'Viladia Sweets', ideal storage is at 1°C, 70-80% RH, 3% O₂, 5% CO₂, 92% N₂.

Table 3: Recommended controlled atmosphere composition for storage of onion bulbs

Carbon dioxide (%)	Oxygen (%)	Temperature (°C)
0	1-2	-
0	1-2	0-5
0-5	1-2	0-5
0-5	0-1	0-5
5	3	1
5	3	1
5	3	-
5	5	4-5
10	3	4-5

Table 4: Recommended controlled atmosphere composition for storage of spring green onion

Carbon dioxide (%)	Oxygen (%)	Temperature (°C)	Comments
5	1	0	Stored for 6-8 weeks
0-5	2-3	0-5	Had only a slight effect
10-20	2-4	-	-
10-20	1-2	0-5°C	Had only a fair effect but was of limited commercial use

Table 5: Environmental regimes used during direct harvest storage system

Stage	Duration	Temperature (°C)	Humidity (%)	Airflow rate 1 tonne ⁻¹)	Comments
I	3-5 days	30-32	-	0.12	
II	20 days (approx.)	26 initially, slowly reduced to 15	65-75	0.048	Removal of surface water
III	As required	0-5	65-75	-	Removal of surface moisture, drying and curing of the skins, and sealing; Completion indicated by rustling of skins when handled
IV	7 days (approx.)	Above dew point of air in grading shed	65-75	-	Minimise respiration, extended dormancy; Up to 10 months storage possible

(Source: Thompson, 1996)

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Medicinal Value of Spine Gourd (*Momordica dioica*)

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Abstract

Spine gourd (*Momordica dioica*), commonly referred to as teasel gourd, kantola, or bristly balsam pear, is a perennial climbing plant belonging to the Cucurbitaceae family. It is native to India and parts of Southeast Asia, and has been used for centuries both as a food and as a traditional medicine. Apart from its culinary versatility, spine gourd offers a range of therapeutic benefits attributed to its rich nutritional and phytochemical profile. This article explores the medicinal properties and health advantages associated with spine gourd consumption.

Nutritional Composition

Spine gourd is an excellent source of dietary fiber, essential vitamins such as vitamin C and vitamin A, and minerals including potassium, iron, magnesium, and calcium. It also contains several beneficial phytochemicals like flavonoids, tannins, alkaloids and saponins. These compounds contribute to the plant's antioxidant, anti-inflammatory, and antimicrobial properties. The low-calorie content combined with high fiber levels makes it an ideal food for weight management and digestive health.

Medicinal Properties

Antioxidant Activity: Spine gourd contains high levels of antioxidants, which help neutralize free radicals in the body. By reducing oxidative stress, these antioxidants protect cells from damage and lower the risk of chronic illnesses such as heart disease, diabetes, and cancer.

Antidiabetic Effects: Several studies suggest that spine gourd possesses antidiabetic properties. Its bioactive compounds may enhance insulin secretion

and improve glucose metabolism, thus aiding in blood sugar regulation. Traditional healers often recommend spine gourd to individuals suffering from diabetes.

Anti-inflammatory Action: Spine gourd exhibits strong anti-inflammatory effects, which help in reducing inflammation associated with chronic conditions like arthritis, asthma, and inflammatory bowel diseases. Regular consumption can contribute to alleviating symptoms of these inflammatory disorders.

Antimicrobial Benefits: Research has demonstrated that spine gourd extracts have antimicrobial properties effective against certain bacterial and fungal strains. This makes it beneficial for boosting the immune system and preventing infections.

Hepatoprotective Effects: Spine gourd has been traditionally used to protect liver health. Its compounds help in detoxifying the liver, promoting bile production, and shielding liver cells from damage caused by toxins or oxidative stress.

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Weight Management and Digestive Health:

Owing to its high fiber and low-calorie profile, spine gourd supports weight management by promoting a sense of fullness. It also aids digestion, helps regulate bowel movements, and prevents constipation.

Traditional and Therapeutic Uses

In Ayurveda and traditional Indian medicine, spine gourd is used to treat a variety of ailments, including fever, skin diseases, constipation, and respiratory issues. Decoctions made from its leaves and fruits are administered for their purgative and anthelmintic properties. The plant is also believed to strengthen the body and improve overall vitality.

Scientific Studies and Modern Research

Recent pharmacological studies have begun to validate many of the traditional claims regarding spine gourd. Research has confirmed its antioxidant, antidiabetic, antimicrobial, and anti-inflammatory activities. Further studies are exploring its potential role in cancer prevention and metabolic disorder management. Given its promising therapeutic potential, spine gourd may become a valuable natural remedy in modern integrative medicine.

Conclusion

Spine gourd is a potent medicinal plant with diverse health benefits. Its rich nutritional profile and bioactive compounds make it effective in preventing and managing several chronic conditions, including diabetes, liver disorders and inflammation. Incorporating spine gourd into the daily diet can enhance health and wellness naturally. As modern research continues to unfold, spine gourd stands out as an

important plant in the landscape of medicinal and functional foods.

Medicinal Value of Bael Fruit

Dev Raj Gurjar, Babli Ranwa, Bhavna and Arpit Goutam

Abstract

Bael (*Aegle marmelos*), also known as Bengal quince or stone apple, is a sacred and highly valued tree native to India and Southeast Asia. Recognized in traditional systems of medicine such as Ayurveda, Unani, and Siddha, bael has been revered for centuries for its immense medicinal properties. Every part of the bael tree from its roots and bark to its leaves, fruit, and seeds offers therapeutic benefits that contribute to human health and well-being.

Nutritional Composition

Bael fruit is rich in nutrients such as:

Vitamins: Vitamin C, Vitamin A, and several B-complex vitamins.

Minerals: Calcium, potassium, iron and phosphorus.

Phytochemicals: Tannins, flavonoids, coumarins, and alkaloids.

Dietary Fiber: Bael pulp is high in fiber, making it excellent for digestive health.

These components collectively contribute to bael's diverse medicinal value.

Medicinal Properties and Uses

Digestive Health: Bael is most famous for its positive effects on the digestive system. The ripe fruit acts as a natural laxative, relieving constipation by promoting healthy bowel movements. Conversely, unripe bael fruit is used to treat diarrhea and dysentery due to its astringent properties that reduce intestinal inflammation. Regular consumption of bael juice strengthens the digestive tract, prevents gastric ulcers, and maintains gut health by reducing harmful bacterial load.

Anti-diabetic Activity: Bael leaves have hypoglycemic properties and are traditionally used to manage blood sugar levels. The active compounds help stimulate insulin production and regulate blood glucose, making bael an effective natural remedy for diabetes management. Drinking bael leaf juice on an empty stomach is a common practice among diabetic patients in traditional medicine systems.

Antimicrobial and Antiviral Properties: Various parts of the bael tree exhibit strong antimicrobial activities. Extracts from the leaves, fruit, and bark are effective against a wide range of bacteria, fungi, and viruses. This makes bael useful in treating infections, wounds, and skin diseases. Its antiviral properties have been studied against several pathogens, suggesting potential use in controlling viral infections naturally.

Respiratory Health: The expectorant properties of bael make it beneficial in treating respiratory ailments like asthma, bronchitis, and cold. The juice extracted from bael leaves mixed with honey is a traditional remedy to relieve congestion and breathi-

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ng difficulties.

Anti-inflammatory and Analgesic Effects: Bael exhibits strong anti-inflammatory and pain-relieving effects. It is used to alleviate inflammation in conditions such as arthritis and injuries. Topical applications of bael leaf paste can soothe swelling and pain in joints and muscles.

Cardiovascular Benefits: The presence of antioxidants in bael fruit helps in reducing oxidative stress, thereby supporting heart health. Bael consumption may help lower blood cholesterol and triglyceride levels, preventing heart diseases and improving overall cardiovascular function.

Liver Protection: Studies have indicated that bael possesses hepatoprotective properties. Its extracts help protect liver tissues from damage caused by toxins and oxidative stress. Regular intake of bael can enhance liver function and aid in detoxification.

Skin and Hair Care: Due to its antimicrobial and antioxidant properties, bael is used in treating various skin conditions like acne, eczema, and infections. The vitamin C content aids in collagen production, maintaining healthy, youthful skin. Bael extracts are also included in hair care formulations to promote scalp health and reduce dandruff.

Traditional Preparations and Usage

Bael Fruit Juice: Made from ripe bael pulp, it is refreshing and medicinal, often consumed during summer to prevent heatstroke and aid digestion.

Bael Leaf Decoction: Used for blood sugar regulation and detoxification.

Bael Root Powder: An ingredient in traditional

medicines for respiratory and digestive disorders.

Bael Oil: Extracted from seeds, used in hair and skin care.

In Ayurveda, bael is classified as tridosha hara, meaning it balances all three doshas Vata, Pitta, and Kapha.

Safety and Precautions

While bael is generally safe for consumption, excessive intake, especially of unripe fruit, may cause digestive discomfort. People with severe diabetes or those taking blood sugar medications should consult a healthcare provider before using bael supplements, as it can potentiate the effects of hypoglycemic drugs. Pregnant and breastfeeding women should also seek medical advice before consuming large amounts of bael products.

Conclusion

Bael is a treasure trove of medicinal benefits. Its rich composition of nutrients and bioactive compounds makes it a versatile remedy for a wide range of health issues. From improving digestion and managing diabetes to promoting heart, liver, and skin health, bael offers holistic healing solutions rooted in ancient traditions. Incorporating bael into the diet, either through fresh fruit, juices or herbal preparations, can significantly enhance overall health and resilience against diseases.

Cultivation of Bitter Gourd under Arid Conditions

Babli Ranwa, Dev Raj Gurjar and Bhavna

Abstract

Bitter gourd (*Momordica charantia*), commonly known as bitter melon, is an important vegetable crop valued for its nutritional and medicinal properties. Growing bitter gourd under arid conditions presents unique challenges such as high temperatures, low rainfall, and poor soil fertility. However, with proper management practices, successful cultivation is achievable.

Climate and Soil Requirements: Bitter gourd thrives in warm climates and is well-adapted to temperatures between 25°C and 35°C. In arid regions, selecting a site with access to irrigation is critical. Well-drained sandy loam soils with good organic matter content and a pH of 6.0-7.0 are ideal. Saline or highly alkaline soils should be avoided.

Variety Selection: Selecting drought-tolerant and heat-resistant varieties is crucial for success in arid regions. Recommended varieties include:

- ✓ Pusa Do Mausami
- ✓ Arka Harit
- ✓ Phule Green
- ✓ CO 1 and CO 2

Land Preparation: The land should be plowed 2-3 times to create a fine tilth. Raised beds or ridges and furrows are recommended to improve drainage and conserve soil moisture. Organic manure (15-20 t ha⁻¹) should be incorporated during land preparation to enhance soil fertility.

Sowing Time: In arid regions, sowing is ideally done at the beginning of summer (February-March) or

early monsoon (June-July) depending on irrigation availability. Direct seeding is common, but transplanting can also be practiced.

Seed Treatment and Sowing: Seeds should be treated with fungicides like carbendazim (2 g kg⁻¹ seed) to prevent seed-borne diseases. Soaking seeds in water for 12-24 hours before sowing improves germination. Spacing should be maintained at 1.5-2.0 meters between rows and 60-90 cm between plants.

Irrigation Management

Due to the arid environment, efficient water management is crucial:

- ✓ Drip irrigation is highly recommended.
- ✓ Irrigate immediately after sowing and then at 5-7 day intervals.
- ✓ Mulching with organic material or plastic can conserve soil moisture and suppress weeds.

Nutrient Management

A balanced fertilization schedule should be followed:

Basal application: 20-25 kg Nitrogen, 40-50 kg

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Phosphorus, and 20-25 kg Potassium ha⁻¹.

Top dressing: Apply an additional 20-25 kg Nitrogen ha⁻¹ after 30 days of sowing.

Foliar sprays of micronutrients (especially zinc and iron) enhance crop growth.

Weed Management: Regular weeding during the initial growth stages is essential. Mulching significantly reduces weed pressure. If necessary, herbicides such as pendimethalin can be applied as pre-emergence.

Pest and Disease Management: Common pests include fruit flies and red pumpkin beetles, while common diseases include powdery mildew and downy mildew. Management practices:

- ✓ Use pheromone traps for fruit fly control.
- ✓ Spray neem oil (5%) or recommended insecticides for pest management.
- ✓ Apply fungicides like sulfur or mancozeb for disease control.

Harvesting: Bitter gourd fruits are harvested when they are still immature and green. Harvesting starts 55-60 days after sowing and continues every 3-4 days. Timely harvesting ensures better quality and prolongs fruiting.

Conclusion

With appropriate variety selection, irrigation management, and cultural practices, bitter gourd cultivation can be successfully achieved even under arid conditions, offering farmers a profitable option for vegetable production.

Nature's Tiny Warriors: Battling Rice Root-Knot Nematodes in North East India with Biological Control

Premi Chanu Soubam and Raghubir Kumar Patidar

Rice the lifeblood of millions in North East India is under siege. A microscopic enemy, the rice root-knot nematode (*Meloidogyne graminicola*), has been silently attacking rice roots, stunting growth, reducing yields causing economic losses and devastating livelihoods. But in the lush, bio-diverse corners of Assam, Manipur and other northeastern states, scientists and farmers are discovering a powerful ally i.e. biological control. Unlike chemical pesticides, which can harm the environment and human health, biological control uses nature to fight nature-unleashing beneficial organisms to target pests. For *M.graminicola*, the most promising bio-control agents include fungi, bacteria and even predatory nematodes.

What is *Meloidogyne graminicola*?

M. graminicola is a plant-parasitic nematode attacking the roots of rice roots. It is characterized by presence of galls or knots on the roots which disrupts the plants mechanism of absorbing water and other essential nutrients. Stunted growth, yellowing of leaves and reduced grain production of crops are some of the important symptoms observed in crops infested by *M. graminicola*. *M. graminicola* has found its perfect breeding ground in the humid and

waterlogged conditions of North-East India which is ideal for rice cultivation. Farmers suffers from devastating yield losses which estimates up to 80% in severely infested fields. Due to its microscopic size and lack of farmer awareness, it has always been underdiagnosed.

Problem with chemical nematicides

The usage of chemical nematicides has been related with some serious issues including:

Environmental hazards: It has the potential to harm the aquatic life from the residues present in the runoff. There is high chances of harming the non-target organisms.

Cost barriers: Most of the small holding North East Indian farmers cannot afford expensive synthetic inputs.

Resistance: Overuse of synthetic chemicals may lead to development of nematode resistance.

Soil degradation: Excessive use of chemicals deteriorates overall soil health and soil micro-flora.

Consequently, there has been a rise in demand for eco-friendly and cost-effective alternatives paving the way for biological control.

Biological Control: Harnessing Nature's Weapons

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Biological control mostly emphasizes on utilizing living organisms viz. fungi, bacteria and other nematodes to manage the pest population to an acceptable level. The biological control agents are eco-friendly, sustainable and cost-effective in nature. Most promising strategies being explored in North-East India are:

Nematophagous fungi

It parasitizes or prey on nematodes. Important species includes:

***Paecilomyces lilacinus*:** It parasitizes on nematode eggs eventually reducing their population before hatching.

***Pochonia chlamydosporia*:** It can penetrate and destroy egg masses of nematodes.

***Trichoderma harzianum*:** It may induce systemic resistance against the nematode pest population. Moreover, it also promotes plant growth.

Field trials in Assam and Meghalaya using the fungal agents have shown a remarkable results, reducing 60% of nematode infestation.

Bacterial Bio-control agents

The following soil bacterial species have antagonistic nature against nematode which can be integrated to the nematode pest management system.

***Pseudomonas fluorescens*:** It can establish in the rhizosphere and the toxin produced by *P. fluorescens* can inhibits nematode pest population and their activity.

***Bacillus subtilis*:** It releases secondary metabolites and lytic enzymes that are harmful for the nematode pest population.

They also promote root growth and enhancing plant vigor that helps rice plants to tolerate stress efficiently.

Mycorrhizal associations: AMF (Arbuscular Mycorrhizal Fungi) such as *Glomus spp.* forms symbiotic relationships with rice roots which improves the uptake of nutrient and creating physical barriers making it difficult for the nematodes to penetrate on to the roots. They also stimulate the immune responses of plants.

Field Applications in North-East India

According to ICAR-NEH 2023, the recent trials using fungal and bacterial agents by ICAR Research Complex for NEH region and Assam Agricultural University have shown successful nematode suppression to a remarkable extent.

Key strategies includes:

- ✓ Seed/Root dipping in *P. lilacinus* or *T. harzianum* suspensions.
- ✓ Soil application of FYM or Compost mixed it with *P. fluorescens*.
- ✓ Dual inoculation with AMF and bacterial antagonists.

Integrated Biological Management: The step forward

Combination of biological with sustainable agronomic practices have resulted in successful management of nematode pest population.

- ✓ Green manuring with legumes such as Sesbania enhances soil health and suppresses nematodes.
- ✓ Crop rotation with non-host crops viz. mustard or pulses disrupts the life cycle of nematodes.

Application of organic amendments such as neem cake and vermicompost enhances microbial activity that suppresses nematode activity.

Numerous Krishi Vigyan Kendras (KVKs) in North East region are providing training to the farming community for efficient adoption of these strategies which helps bridge the gap between research and the field.

Challenges and future directions

Biological control comes with several challenges even though it holds great promises:

- ✓ The lack of awareness among the small holder farmers which may be improved through extension programs.
- ✓ Limited mass production and availability of bio-control agents.
- ✓ Requirement of conducting more research on field consistency of bio-control agents under variable environmental conditions.

Ongoing research studies in institutions such as Assam Agricultural University and ICAR Research Complex for NEH region are addressing these gaps and developing locally adapted bio-control formulations.

Conclusion: A solution to sustainability

As India strives for food security and sustainable agriculture, biological control of *M. graminicola* offers a beacon of hope. By accepting the biological control method, farmers in North-East India are not just managing pests, they are protecting ecosystem, improving soil health and securing the future of rice cultivation. The future of rice crop lies

not just in fighting pests but also in restoring balance with nature.

Nutrient Dynamics in Submerged Soils: Implication on Crop Productivity

Sameer Kumar, Neha Chauhan, N. K. Sankhyan, Pradeep Kumar, Siddhant Lanjewar and Chhaviraj Baghel

Abstract

Submerged soils are globally important both in natural and agricultural ecosystems and cover 5-7 per cent of the global land surface. They are important for global food production (e.g. rice), nutrient cycling and biodiversity. Therefore, processes in submerged soils are important for global biogeochemical cycles. In submerged soils, O₂ is depleted by aerobic microbes because O₂ diffusion rates in water are four orders of magnitude lower than in air, limiting O₂ replenishment from the atmosphere. Hence, the most distinct chemical characteristic of submerged soils is their reduced state. The factors like soil organic-matter content, type of soil, pH and temperature in such soils determine the extent of chemical changes taking place. The reduction of Fe³⁺ to Fe²⁺, Mn⁴⁺ to Mn²⁺, NO³⁻ and NO²⁻ to N₂, SO₄²⁻ to S₂ and CO₂ to CH₄ take place in flooded soils. The redox reactions influence the chemical status of soils under submerged conditions. The availability of essential plant nutrients is influenced by these changes. The availability of P, K, Fe, Mn, Mo and Si increases in flooded soils, while the availability of S, Zn and Cu decreases.

Introduction

Globally, the impact of soil waterlogging on crop yield has been extensively documented. Studies have shown that waterlogging events during different growth stages such as seedling, jointing and tillering resulted in varying levels of yield reduction across crop varieties. Moreover, significant variations in yield reduction have been observed

depending on the crop growth stage at the time of waterlogging (Tian *et al.*, 2021). Although natural wetlands and paddy rice cover only a small proportion of global land surface, they contain about a third of the total soil organic C (OC) and contribute a third to global methane emissions (Neori and Agami, 2017). So, study of submerged soil is prevalent now-a-days.

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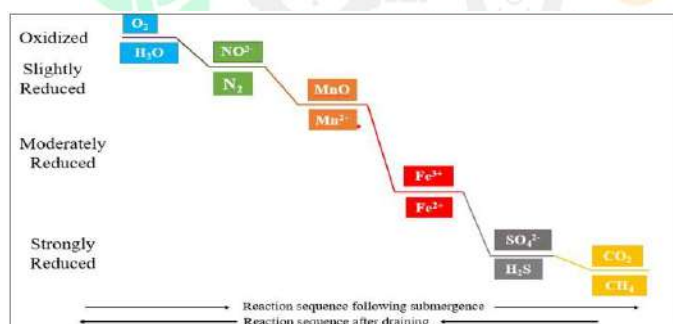
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Submerged soils are the soils that are submerged in water for a sufficient period of time to give the distinct horizon development differentiating from other soils. In submerged soils, O_2 is depleted by aerobic microbes because O_2 diffusion rates in water are four orders of magnitude lower than in air limiting O_2 replenishment from the atmosphere. Hence, the most distinct chemical characteristic of submerged soils is their reduced state (Marschner, 2021).



Nutrients dynamics: Nutrient dynamics is broadly defined as the way nutrients are taken up, retained, transferred and cycled over time and distance in an ecosystem. These processes are interlinked with reduction of these element present in submerged soils.

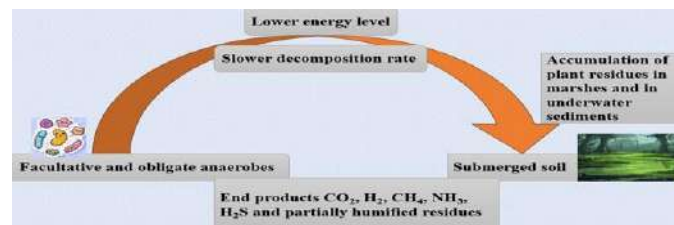


Chemical reduction sequence following submergence

Transformation of different nutrient elements in submerged conditions

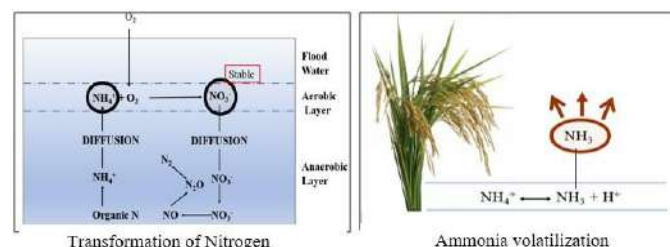
Carbon: In submerged soils, respiration (decomposition of organic matter) is the primary transformation. The decomposition of OM is carried out almost entirely by facultative and obligate anaerobes. These facultative and obligate anaerobes operate at much lower energy than aerobic organism

leading to the accumulation of residues in marshes and underwater sediments. The end product of these anaerobic decomposition includes CO_2 , H_2 , CH_4 , NH_3 , H_2S and partially humified residues.



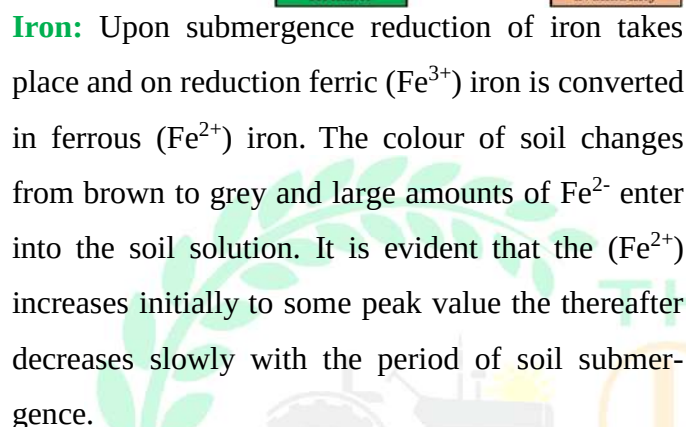
Transformation of Carbon

Nitrogen: There are various pathways through which Nitrogen (N) is transformed in submerged soils which include ammonification, nitrification and denitrification, ammonia volatilization, biological nitrogen fixation and leaching. In submerged soil ammonia volatilization is the major cause of N loss. In aerobic layer conditions are similar to those in well drained soils and transformation proceeds towards NO_3^- formation. The presence of aerobic layer above anaerobic layer is the major cause of instability of nitrogen in submerged soils and results in considerable loss of N through nitrification - denitrification reaction. Once ammonia gas (NH_3) is formed it lost in the atmosphere through ammonia volatilization.

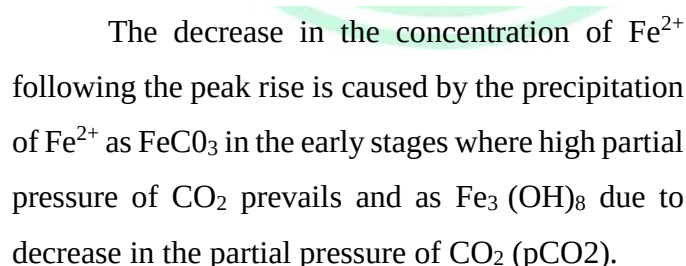


Potassium: Initially there is increase in available Potassium (K) upon submergence. With flooding or submergence soluble ferrous (Fe) and manganous (Mn) ions increase and exchangeable K is then displ-

reduction results from the soil submergence, it may react with various heavy metals (Zn, Cu, Cd, Pb etc.) to give their insoluble sulphides. As a result, the availability of these metals may be reduced. Because Fe^{3+} reduction to Fe^{2+} precedes SO_4^{2-} reduction, there usually will be Fe present in the soil solution by the time hydrogen sulphide H_2S is produced and to that hydrogen sulphide will be converted to insoluble iron sulphide (FeS).



Manganese: In submerged soil transformation of Mn results in increase in concentration of water soluble Mn^{2+} and later precipitation of Manganous carbonate ($MnCO_3$). When the aerobic laterite soils are submerged, the reduction of Mn^{4+} occurs almost concurrently with nitrate reduction, but this reduction proceeds that of Fe reduction. The concentration of Mn^{2+} (water soluble) increases initially and then after decline with period of submerges.



Conclusion

Submerged soils undergo a series of redox reactions, leading to the reduction of various elements with subsequent effects on nutrient availability. Essential nutrients like phosphorus (P), potassium (K), iron (Fe) and manganese (Mn) become more available under submerged conditions and elements such as sulphur (S), zinc (Zn) and copper (Cu) tends to decline. Carbon transformation in submerged soils leads to formation of CH₄ and others different elements. Enhanced ammonification and denitrification are common under anaerobic conditions, contributing to nitrogen loss through

volatilization and leaching. Phosphorus availability increases in submerged soils due to the reduction of iron-phosphate complexes, enhancing its uptake by crops.

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The Prospect of Stingless Bee Rearing in Terai Region of West Bengal, India

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Introduction

West Bengal's agriculture predominantly relies on smallholder farms and the integration of stingless bee rearing can offer a supplementary income source for farmers, thus enhancing their economic resilience. Beekeeping, in general, necessitates minimal land and labor as compared to crop cultivation, rendering it suitable for implementation by rural populations (Dia *et al.*, 2018). The technology needed for beekeeping is not complex and requires little capital to start with, enabling rural communities to generate employment and supplement their income through scientific beekeeping (Berhe *et al.*, 2016; Kumar *et al.*, 2020). The terai region of West Bengal possesses a diverse agro-climatic landscape that presents a unique opportunity for the advancement of apiculture, specifically stingless bee rearing (*Tetragonula iridipennis* Smith), also known as meliponiculture. Stingless bees, belonging to the tribe Meliponini within the family Apidae, are native to tropical and subtropical regions across the globe and are recognized for their crucial role in pollination services for both crops and wild plants (Nunes-Silva *et al.*, 2016).

These bees produce honey, pollen, wax, and propolis (or cerumen), with honey being particularly valued for its perceived health benefits since ancient times (Herwina *et al.*, 2021). Stingless bee honey contains valuable compounds like tannin, flavonoids, coumarin, and carbohydrates, while lacking steroids and carotenoids (Herwina *et al.*, 2021). Stingless Beekeeping is known as “meliponiculture”. Only drawback is they produce less honey. On an average a single bee colony can provide somewhere around 200 grams to 1 kg of honey in a year. This also depends on how big the colony is and nectar available locally. However some farmers have been able to get 2 to 3 kg from healthy colony once in a while. Cheruthen (Stingless bees honey) is considered superior honey in Ayurvedic texts and other medical journals. It is mostly administered to kids for mild fever.

Prospect of stingless bee rearing

The terai region of West Bengal comprising three districts namely Jalpaiguri, Cooch Behar and Alipurduar, the practice of beekeeping is largely cantered on the European honey bee (*Apis mellifera*) and the Indian honey bee (*Apis cerana indica*), with

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stingless bees remaining a significantly underutilized resource. Considering the ecological and economic advantages associated with stingless bee rearing, exploring its potential in terai region of West Bengal is of paramount importance. Furthermore, the honey produced by stingless bees possesses distinct organoleptic properties and potential medicinal value, which can attract niche markets and fetch premium prices as a large number of Farmers Producer Companies are functional in the regions. The conservation of stingless bees contributes to the overall biodiversity and ecosystem health of the region. Moreover, promoting stingless bee rearing aligns with sustainable agricultural practices, as it reduces the reliance on synthetic pesticides and promotes natural pollination mechanisms. In fact, honeybees are crucial to the agricultural economy because they efficiently pollinate numerous agricultural crops globally (Li *et al.*, 2018). Beekeeping contributes not only to honey production but also plays a vital role in ensuring food and nutrition security by pollinating up to 30% of global food production (Landaverde *et al.*, 2023) and *Tetragonula* increased the number of fruits and quality of strawberry and cucumber grown under green house condition.

Work on stingless bee rearing in India

The work on stingless bee is particularly located in the southern states of India. Stingless bees are exceptional and incredible, and are found in most tropical or subtropical regions of the world (Kichu and Bhattacharya, 2020). The study by Bisui *et al.*

2020 on effect of pollination service by *Tetragonula irridipennis* on bitter gourd indicated that the quality of the bitter gourd fruits improved in managed bee-pollinated systems in comparison to an open pollination system. The authors recommended that farmers can use Indian dammar bee colonies in their agricultural land to increase the quantity and quality of the yield of bitter gourd. Similarly, Gramajanya FPC Ltd. Working at Puttur, Dakshina Kannada, it is promoting apiculture by launching an event 'honey at every home' initiative to promote meliponiculture (stingless bee keeping) in urban areas of the district. The FPC is arranging the bee box with the colony of stingless bees to urban dwellers on demand on the price fixed by the FPC. Since there is no fear of sting bite anybody can go for meliponiculture. People living in apartments, individual homes and gated communities can take up this stingless bee keeping. Many people buy honey of bigger bees regularly however they are not willing to keep them in their farm or garden because of the aggressive nature. For such people and farmers stingless honey bee is the best option. Cooch Behar Krishi Vigyan Kendra under the aegis of Uttar Banga Krishi Viswavidyalaya started awareness generation among the rural farmers about the conservation and promotion of stingless bee rearing as alternate income generation options and pilot demonstrations are in progress to observe the pollination efficiency of *T. irridipennis* in cucurbitaceous crops particularly bitter gourd, water melon, cucumber etc.

Advantages of stingless bee rearing: In natural nesting shelters, the honey is stored in pots and kept intermingled with pollen pots and brood. In devised wooden boxes, it is possible to keep honey storage separate from other contents of the colony and hence the honey can be obtained without any damage to the brood. The some of the advantages of stingless bee rearing may be summarized as:

- ✓ The production of high valued medicinal honey, the other products such as pollen and propolis can also be obtained and marketed to get higher income.
- ✓ Being stingless, rearing of these bees in devised wooden boxes can be easily done by women farmers with no or less fear of stinging.
- ✓ The technology for rearing of stingless bees can be adopted in semi-urban areas by the unemployed but educated youths.
- ✓ Migration of stingless bee colonies to areas having plenty bee flora for getting higher honey which will fetch more price in turn.
- ✓ The stingless bees are efficient pollinators of many agricultural and horticultural crops and pollination services in target crops can be supplemented keeping colonies in fields.
- ✓ Stingless bee keeping can be practiced for achieving desired pollination in high valued crops under protected cultivation (polyhouses).
- ✓ Devised rearing technique would help conservation of the valuable stingless honey bee species in terai regions, maintaining the overall biodiversity, additional direct and indirect income

to the farmers, unemployed youths and women.

Challenges and limitations

The success of stingless bee rearing in terai region of West Bengal hinges on addressing several key challenges and opportunities. One of the primary limitations is the lack of awareness and technical expertise among farmers regarding stingless bee management practices. Targeted training programs and extension services by line departments are essential to educate farmers about colony management, hive construction, honey harvesting techniques, and pest and disease control. Another significant aspect is the need for research and development to identify suitable stingless bee species that are well-adapted to the local climate and agricultural systems fitted to terai regions of West Bengal. Establishing demonstration farms and pilot projects by Krishi Vigyan Kendra or Uttar Banga Krishi Viswavidyalaya can showcase the benefits of stingless bee rearing and encourage wider adoption among farming communities. Preserving nectar and pollen sources through vegetation management techniques is vital for sustaining stingless bee colonies, as well as maintaining optimal colony numbers (Priyambodo *et al.*, 2023). Furthermore, regulations and standards are needed to safeguard the safety, quality, and authenticity of this priceless natural product (Gadge *et al.*, 2024). The implementation of sustainable beekeeping practices is crucial to avoid any potential harm to wild bee populations. Additionally, proper care is needed to limit the impacts of extreme climatic conditions (Vercelli *et*

al., 2021). Institutional and financial support for the beekeeping sector must be strengthened and better targeted to address specific issues arising from climatic stresses (Vercelli *et al.*, 2021). Creating market linkages and value chains for stingless bee products is also essential to ensure fair prices and market access for beekeepers.

Conclusion

Stingless bee rearing holds considerable promise for terai region of West Bengal, India, offering ecological, economic, and social benefits. The region can harness the full potential of stingless bees by implementing appropriate policies, research initiatives and community-based programs, contributing to sustainable agricultural development, biodiversity conservation, and the empowerment of rural communities. By implementing targeted interventions, promoting research and development, and fostering collaboration among stakeholders, West Bengal can unlock the full potential of stingless bee rearing and create a more sustainable and prosperous future for its rural communities (Adal *et al.*, 2015; Schouten and Lloyd, 2019).

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Progress and Innovations in Integrated Nutrient Management for Cereal Crop Production

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Abstract

Integrated Nutrient Management (INM) optimizes nutrient use to enhance soil fertility and crop productivity while promoting long-term agricultural sustainability. It balances organic, inorganic, and biological inputs, reducing dependency on chemical fertilizers. INM encourages the use of farmyard manure, compost, crop residues, biofertilizers, and mineral fertilizers, ensuring efficient nutrient recycling. Practices like crop rotation, green manuring, and judicious fertilizer application enhance nutrient use efficiency, stimulate microbial activity, and improve soil health. INM boosts crop yields, improves soil structure, and reduces environmental pollution. It promotes economic sustainability by lowering input costs. Crops like wheat, maize, barley, and rice benefit from INM through higher yields, better quality, and improved soil fertility. INM is a sustainable solution addressing modern agricultural challenges and improving long-term productivity.

Introduction

The rapid increase in global population has placed enormous pressure on agricultural systems, leading to over-exploitation of land resources and widespread soil degradation. Intensive cropping to meet food demand has contributed significantly to the decline in soil quality. According to estimates, food production must increase by about 70% by 2050 to feed the growing population, requiring an annual increase of nearly 43 million metric tonnes of grain production (Hunter *et al.*, 2009). To meet this challenge sustainably, Integrated Nutrient Management (INM) has emerged as a vital approach. INM refers to the combined and balanced use of chemical fertilizers, organic manures, crop residues, and biofertilizers to supply essential nutrients to crops.

This strategy not only enhances nutrient availability and uptake but also maintains soil fertility, minimizes environmental pollution, and supports long-term agricultural productivity (Albahri *et al.*, 2023). Overuse of chemical fertilizers, especially in areas where multiple cropping systems are practiced annually, can lead to nutrient imbalances, soil acidification, and long-term productivity loss. Moreover, the financial burden of synthetic fertilizers is often unsustainable for small-scale farmers. In contrast, organic inputs like farmyard manure (FYM), compost, and green manure have been used for centuries to improve soil health and crop performance. These inputs increase microbial activity, improve soil structure, and enhance the crop's ability to absorb nutrients efficiently (Iqbal *et*

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al., 2019). Modern INM concepts focus on a system-based approach that combines traditional knowledge with scientific principles. By reducing the excessive use of synthetic fertilizers and pesticides, INM supports environmentally responsible farming practices (Haddad *et al.*, 2010). However, successful implementation of INM requires collaboration among various stakeholders government bodies, research institutions, extension workers, non-governmental organizations (NGOs), and farmers themselves (Wu and Ma, 2015).

India, for instance, possesses vast natural resources that can be harnessed for nutrient management, including livestock manure, urban and rural compost, crop residues, green manures, and biofertilizers (Manna *et al.*, 2018). These organic resources help restore the physical, chemical, and biological integrity of the soil. Vermicompost and FYM are particularly effective in replenishing soil organic matter, while crop residues can significantly improve the efficiency of applied fertilizers. Vermicompost also plays a role in reducing the harmful effects of synthetic fertilizers on soil health (Kumar *et al.*, 2018). The primary objective of INM is to maintain or improve soil fertility and ensure the sustainable production of crops. It involves the site-specific application of mineral fertilizers, organic amendments (such as FYM, compost, green manure, crop residues), and biofertilizers (like Rhizobium, Azotobacter, and phosphate-solubilizing bacteria) tailored to local agro-ecological and socio-economic conditions (Kumari *et al.*, 2023).

Scientific studies have demonstrated that INM significantly benefits crop productivity, particularly in cereal crops. In rice, for example, integrated nutrient practices have been shown to optimize nutrient supply, reduce losses, lower input costs, and enhance resilience against both biotic (pests, diseases) and abiotic (drought, salinity) stresses (Janssen, 1993; Prasad *et al.*, 2002; Zhang *et al.*, 2012). In conclusion, Integrated Nutrient Management is a forward-looking agricultural approach that ensures efficient nutrient utilization, improves soil health, and secures food production sustainably. Especially for developing nations with high population growth and limited resources, INM presents a viable path toward achieving long-term food security and ecological balance. This chapter explores the concepts, objectives, principles, and methods of INM, with a focus on its application in major cereal crops wheat, rice, and maize and discusses future opportunities for its advancement in sustainable agriculture.

Objective of Integrated Nutrient Management

- ✓ Minimize the Overdependence on Synthetic Fertilizers
- ✓ Crop Yields without Compromising Soil Health
- ✓ Utilize Locally Available Nutrient Resources Efficiently
- ✓ Narrow the Gap Between Nutrient Application and Crop Uptake
- ✓ Improve the Soil's Physical, Chemical, and Biological Properties
- ✓ Promote Soil Health through Balanced Nutrient

Supply from Diverse Sources

- ✓ Reduce the Negative Effects of Prolonged Chemical Fertilizer Use
- ✓ Strengthen the Economic Stability of Farmers
- ✓ Increase Fertilizer Use Efficiency (FUE)

Basic Principles of INM

Optimized Nutrient Supply: Ensure that crops receive the right amount of nutrients at the right time and place to achieve targeted yields.

Balanced Use of Nutrient Sources: Combine chemical fertilizers, organic manures, crop residues, and bio-fertilizers based on soil fertility status, crop needs, and environmental considerations.

Soil Health Improvement: Enhance soil physical properties like structure, moisture retention, and aeration, as well as chemical and biological properties, to support sustainable crop production.

Traditional Use of INM for Soil Fertility Maintenance

Continuous Nutrient Supply: Provide a steady release of nutrients throughout the crop growth period by integrating organic and inorganic sources.

Nutrient Synchronization: Match nutrient release from soil and applied sources with crop uptake patterns to maximize efficiency.

Soil Health Promotion: Improve overall soil health, including its physical, chemical, and biological aspects, through the use of organic amendments and conservation practices.

Environmental Protection: Reduce nutrient leaching and gaseous losses, thereby minimizing negative impacts on water bodies and the atmosphere.

Components of INM

INM comprises various components that contribute to nutrient supply and soil health: Compost, Green Manure, Crop Residues, Chemical Fertilizers, Manure, Bio-fertilizers

Advantages of INM

Improved Nutrient Availability, Balanced Nutrition, Environmental Conservation, Sustainable Food Production, Cost Reduction

Effect of INM on Different Crops

Wheat: Studies have shown that integrating 75% of the recommended chemical fertilizers with organic sources like vermicompost and bio-fertilizers such as Azospirillum and phosphate-solubilizing bacteria (PSB) can significantly enhance wheat yield and profitability.

Maize: Applying 100% of the recommended chemical fertilizers along with vermicompost and Azospirillum has been found to increase maize grain yield and improve soil health.

Rice: Incorporating 75% of the recommended chemical fertilizers with organic amendments like farmyard manure and bio-fertilizers has led to improved rice yields and better soil nutrient status.

Barley: Combining 100% of the recommended chemical fertilizers with vermicompost and Azotobacter has resulted in increased barley yield and enhanced soil fertility.

Conclusion

Integrated Nutrient Management (INM) is a sustainable strategy that enhances crop productivity, preserves soil health, and minimizes environmental

impacts by combining organic and inorganic nutrient sources. It ensures a balanced nutrient supply for better plant growth and higher yields, while improving soil structure and boosting microbial activity. INM reduces reliance on synthetic fertilizers, helping mitigate water pollution and lower carbon emissions. Economically, it saves costs by increasing nutrient use efficiency and reducing fertilizer expenses. INM also improves soil resilience to stressors like drought and degradation, making it a holistic approach to sustainable agriculture, especially for cereal crops.

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The Socio-Economic Status and Challenges of Indian Fishermen Community

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Introduction

Fisheries involve both culture and capture fisheries, playing an important role in the Indian economy and food security (FAO, 2024). India accounts for around 7% of the world's fish production, with a total of around 28 million people involved in fisheries and aquaculture. This research identifies the present scenario of Indian fishermen, their socio-economic issues and government intervention to enhance their living standards. India is the second-largest aquaculture fish producer in the world. Fisheries and aquaculture contribute around 1.1% of the country's GDP, with an annual value addition of INR 1.75 trillion (Sathianandan, 2022). India has rich fishery resources in the form of a 2.02 million square kilometer Exclusive Economic Zone (EEZ) and 7.5 million hectares of inland water bodies (CMFRI, 2023).

Socio-Economic Status of Indian Fishermen

Fishermen are a key component of food security and employment generation. The industry gives direct livelihood to nearly 25 million individuals and sustains millions more in the value chain (Narwadkar *et al.*, 2022). Fishermen, however, are confronted with serious socio-economic limitations, such as low earnings, limited access to contemporary technology, and susceptibility to clim-

atic fluctuations. Small-scale and traditional fishers dominate the sector, producing a significant proportion of marine and inland fish but tending to lack financial security (Aher *et al.*, 2022).

Age and Workforce Composition: India's fishing labor force is mostly middle-aged, with 37.5% being 41-50 years old (Kalita and Deka, 2015). Youth involvement is restricted owing to occupational stigmatization and out-migration to urban sectors, worsening an aging labor force. There are regional differences; in Maharashtra's Ekruk Reservoir, the age group of 35-54 years dominates, showing dependency on veteran laborers (Kumbhar, 2017).

Educational: Illiteracy remains a key impediment, as 42.2% of marine fishermen are not formally educated (CMFRI, 2010). Gaps are wide: Assam has 63% illiterate fishermen and just 13.9% completing primary education (Sheikh and Goswami, 2013).

Income and Economic Vulnerability: Monthly incomes range from ₹5,000-8,000 for traditional fishermen, and 61% are BPL (CMFRI, 2010). Women, making up 30-40% of the workforce, are subjected to wage discrimination, receiving 50% lower than men for post-harvest work (FAO, 2024).

Housing: More than 70% of them live in semi-pucca or kutcha houses, which may or may not have sanitation facilities. Assam has 85% living in tin-

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roofed mud houses, with <2% using toilets (Kalita and Deka, 2015). These conditions are associated with widespread waterborne diseases (Sheikh and Goswami, 2013).

Caste and Social Marginalization: SC/ST groups control coastal areas, with 50-60% representation in Odisha and West Bengal (CMFRI, 2010). Socio-economic stratification is perpetuated by caste-based exclusion from credit and technology.

Health Status and Occupational Hazards

Physical Health Risks: Fishing is one of India's most risky professions. Musculoskeletal conditions (14.4%) and respiratory diseases (13.6%) dominate as a result of repetitive work and exposure to saline environments (Parasuram *et al.*, 2015). In Gujarat, 30.3% are affected with skeletal fluorosis due to contaminated groundwater (John *et al.*, 2015). Dental caries (82.6%) and periodontal disease (85.4%) are prevalent, attributed to tobacco consumption and poor personal hygiene (Asawa *et al.*, 2014).

Mental Health and Substance Abuse: Pressure of financial insecurity and work-related dangers fuels addiction: 64.2% chew tobacco and 45.6% drink alcohol (Rane *et al.*, 2016). In Tamil Nadu, 17.1% are a daily smoker and 22.9% a smokeless tobacco user (Annadurai *et al.*, 2018).

Climate-Related Health Impacts: Increased sea temperatures and cyclones increase health hazards. Post-cyclone Tauktae (2021), Gujarat documented a 40% increase in injuries and infection among fishers (Narwadkar *et al.*, 2022).

Government Policies

Pradhan Mantri Matsya Sampada Yojana (PMM SY): Targets to achieve sustainable development of fisheries at an investment of INR 20,050 crore (Department of Fisheries, 2023).

Fisheries and Aquaculture Infrastructure Development Fund (FIDF): Offers concessional financing for infrastructure schemes (CMFRI, 2023).

Kisan Credit Card (KCC) for Fishermen: Provides access to credit for the purpose of meeting operational costs (FAO, 2024).

Conclusion

Indian fisheries have the potential to contribute to economic development and food security. Yet socio-economic limitations, overuse of resources and environmental issues require integrated policy responses. Technological upscaling, improving financial assistance, and facilitating sustainable practices can go a long way towards enhancing the livelihoods of fishermen. An important area for future study is bringing artificial intelligence and machine learning into fisheries management to utilize resources more effectively and ensure economic viability.

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Post-Harvest Techniques for Mushrooms: A Scientific Approach to Quality Preservation

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Abstract

Mushrooms known for their nutritional value and culinary applications, face significant post-harvest challenges due to their high moisture content, rapid metabolic activity, and susceptibility to microbial spoilage. This article explores the scientific methods involved in post-harvest handling, including harvesting techniques, cooling practices, packaging, drying, and novel preservation technologies. It highlights the mechanisms underlying the deterioration of mushrooms post-harvest and provides insights into current strategies to extend their shelf life while maintaining their sensory and nutritional qualities.

Introduction

Mushrooms, classified as edible fungi, are produced globally for their health benefits, rich flavour, and versatility in various culinary applications. Species such as *Agaricus bisporus* (button mushroom), *Lentinula edodes* (shiitake), and *Pleurotus ostreatus* (oyster mushroom) are among the most widely cultivated. However, mushrooms are highly perishable due to their unique biological properties. With a water content of approximately 90-95%, mushrooms are prone to rapid spoilage post-harvest, a challenge compounded by their high respiration rate and lack of natural protective barriers. The delicate nature of mushrooms makes them vulnerable to both physical damage and microbial contamination, thus posing challenges in maintaining their freshness and quality after harvest.

This article reviews on the post-harvest techniques employed to mitigate these challenges, with an emphasis on the scientific mechanisms that govern spoilage and the methods used to extend the shelf life of mushrooms. These techniques include harvesting methods, cooling strategies, modified atmosphere packaging (MAP), drying technologies, and the application of emerging preservation technologies.

Mechanisms of Mushroom Deterioration Post-Harvest

The rapid deterioration of mushrooms post-harvest is influenced by several biological and environmental factors:

Respiration and Metabolic Activity: Even after the harvest, mushrooms continue to metabolize, consume oxygen and release carbon dioxide.

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This process is known as respiration. It leads to the depletion of sugars, which are crucial for maintaining the texture and flavour of the mushrooms. The higher the respiration rate, the quicker is the deterioration.

Water Loss: Due to their high moisture content requirement, mushrooms are susceptible to dehydration. Water loss accelerates wilting, shrivelling, and browning. It negatively impacts the sensory quality of mushrooms.

Microbial Growth: Mushrooms are prone to contamination by bacteria, moulds, and yeasts. The moist environment in which they are stored provides an ideal breeding ground for microbial pathogens, leading to spoilage and contamination. Understanding these mechanisms is essential for developing strategies that can extend the shelf life of mushrooms and preserve their freshness.

Harvesting Techniques

Harvesting is a critical step that can influence the quality and longevity of mushrooms. Proper handling during harvesting is necessary to minimize physical damage and microbial contamination:

Timing: Mushrooms should be harvested at the optimal stage of maturity. For species like *Agaricus bisporus*, it should be harvested when the cap is fully expanded but not yet flattened. In case of overripe mushrooms, where the cap is too open and the gills exposed, are more prone to microbial colonization.

Handling: Mushrooms should be handled with care during harvesting to avoid mechanical damage, which can lead to accelerated spoilage. Harvesting should ideally be done with clean, sharp tools to

avoid contaminating the fruit body. Twisting or cutting at the base of the stem without damaging the mycelium or substrate can also help in encouraging subsequent flushes in some species.

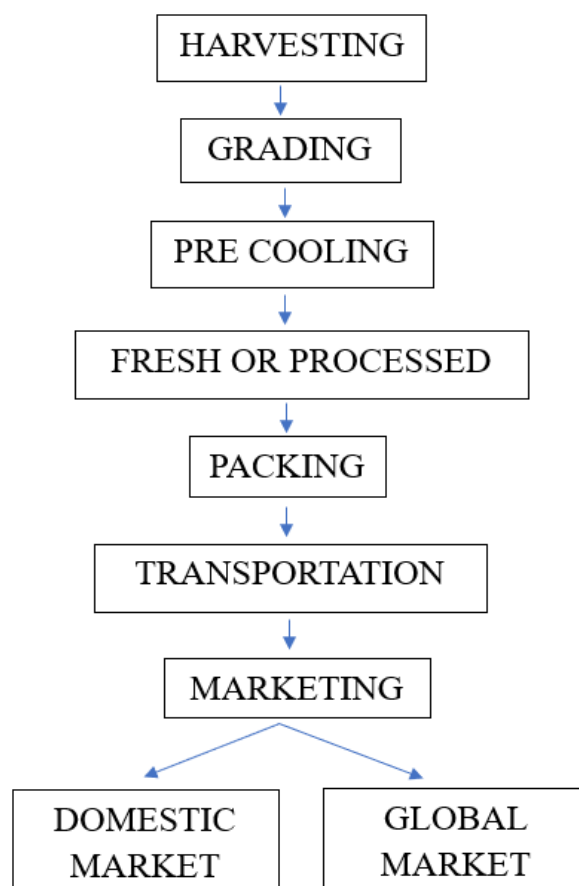


Fig. 1: Post Harvest Process

Post-Harvest Cooling and Storage

Mushrooms are highly perishable due to their high metabolic rate, which can be slowed by reducing the ambient temperature. Cooling plays a pivotal role in extending the shelf life of harvested mushrooms:

Rapid Cooling: Immediate cooling of mushrooms to temperatures between 2-4°C after harvest is essential. Rapid cooling helps to reduce respiration and microbial growth. Vacuum cooling is an effect-

ive method used in commercial mushroom production. It involves applying reduced pressure to rapidly cool mushrooms, effectively removing heat from the product while minimizing moisture loss.

Cold Storage: After cooling, mushrooms should be stored at temperatures between 2°C and 4°C, with relative humidity levels maintained around 85-95%. This temperature and humidity range slows the metabolic activity of the mushrooms, thus extending their shelf life and preserving their quality.

Shelf Life: Proper cooling and storage conditions can extend the shelf life of fresh mushrooms from a few days to 7-10 days, depending on the species and storage conditions.

Modified Atmosphere Packaging (MAP)

One of the most effective methods for extending the shelf life of mushrooms is the use of Modified Atmosphere Packaging (MAP). This technique alters the atmosphere inside the packaging by reducing oxygen levels and increasing carbon dioxide, thus slows down the respiration rate:

Gas Composition: A typical MAP formulation for mushrooms involves reducing oxygen levels to around 5-10%, increasing carbon dioxide to 10-20%, and maintaining nitrogen levels at around 80%. The reduced oxygen slows respiration, while the increased carbon dioxide suppresses microbial growth.

Packaging Materials: Perforated polyethylene or polypropylene films are commonly used in MAP systems. These films allow gas exchange while maintaining the internal humidity of the packaging.

The perforations are carefully designed to match the respiration rates of the mushrooms, ensuring optimal gas exchange.

Drying Techniques

Drying is a time-tested method for preserving mushrooms for longer periods. It removes the majority of the water content, making the mushrooms less susceptible to microbial growth and enzymatic activity. There are several methods of drying, each with its own advantages:

Hot Air Drying: This method involves using warm air to remove moisture from mushrooms. Temperatures typically range from 50-60°C. Hot air drying is cost-effective, though it can result in some loss of flavor and nutrients due to the high temperatures.

Freeze Drying: Freeze drying is the most effective method for preserving the flavor, texture, and nutritional content of mushrooms. In this process, mushrooms are frozen and then subjected to a vacuum that causes the water to sublime directly from ice to vapor. Freeze-dried mushrooms can be rehydrated to retain most of their original qualities and have a shelf life of up to several years.

Microwave-Assisted Drying: This emerging technology combines microwave radiation with hot air to reduce drying time while maintaining the quality of the mushrooms. It offers a more energy-efficient solution compared to conventional drying methods.

Emerging Technologies in Mushroom Preservation

In addition to traditional methods, there are

several innovative technologies that are being explored to enhance mushroom shelf life:

Edible Coatings: Natural edible coatings, such as those derived from chitosan (a biopolymer from crustacean shells), form a protective barrier on the mushroom surface, reducing water loss and protecting against microbial contamination. These coatings can be combined with antimicrobial agents to further extend shelf life.

Ultrasound and Pulsed Electric Field (PEF) Treatments: Non-thermal methods like ultrasound and PEF are being investigated for their potential to reduce microbial contamination and improve the texture and nutritional retention of mushrooms without compromising their flavour.

Ozone Treatment: Ozone has potent antimicrobial properties and is used as a treatment to sanitize mushrooms without the use of chemical preservatives. It is particularly effective in controlling surface microbial contamination and extending shelf life.

Conclusion

Mushrooms are a perishable commodity, and effective post-harvest management is crucial to maintaining their quality and extending their shelf life. By understanding the mechanisms of deterioration and employing techniques such as proper harvesting, cooling, modified atmosphere packaging, drying, and emerging technologies, the shelf life of mushrooms can be significantly improved. Continued research and technological innovation will play a key role in developing sustain-

able and efficient methods to meet the growing demand for fresh and processed mushrooms worldwide.

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Collaboration of Extension Worker and Researcher for Farmer Development

Elammathy K., S. Dineshkumar and Gowtham A. V.

Abstract

Effective collaboration between extension workers and researchers is fundamental to achieving sustainable agriculture. When these two groups work closely together, they ensure that scientific research is effectively translated into practical solutions for farmers. Extension workers play a critical role in disseminating research findings and training farmers to adopt resource-efficient practices, such as precision agriculture, water conservation techniques, and integrated pest management. At the same time, researchers benefit from the field insights and feedback provided by extension workers, allowing them to refine and adapt their innovations to real-world challenges. This synergy not only improves the efficient utilization of resources but also promotes environmentally sustainable and climate-resilient agricultural practices. Ultimately, the collaboration between extension services and researchers drives agricultural advancements that balance productivity with the preservation of natural ecosystems, contributing to long-term food security and resource sustainability. Agricultural extension acts as a bridge between research and practice. In this article, we will learn about the relationship between extension worker and researcher. Also, how extension workers play a critical role in bridging this gap and how important an extension worker in farmer development.

Introduction

Extension education is an applied science consisting of content derived from research, accumulated field experiences and relevant principles drawn from the behavioral science synthesized with useful technology into a body of philosophy, principles, content and methods focused on the problems of out of school education for adults and youth - J.P. Leagans (1961).

The goals of agricultural extension includes transferring information from the global knowledge

base and from local research to farmers, enabling them to clarify their own goals and possibilities, educating them on how to make better decisions, and stimulating desirable agricultural development (van der Ban and Hawkins, 1996). Thus, extension services provide human capital enhancing inputs, including information flows that can improve rural welfare an important outcome long recognized in the development dialogue (Leonard, 1977; Garforth, 1982; Jarrett, 1985; Feder, Just and Zilberman, 1986; Roberts, 1989).

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Role of Agricultural Extension

Education and Training: Extension agents or officers offer training programs, workshops, and field demonstrations to teach farmers about new agricultural methods, pest management, soil fertility, and other relevant topics.

Advisory Services: Extension services provide personalized advice to farmers, helping them solve specific problems and make informed decisions regarding crop management, livestock care, and resource use.

Technology Transfer: Facilitating the adoption of new technologies, such as improved seed varieties, advanced irrigation techniques, or modern farm machinery, is a significant part of extension work.

Information Dissemination: Extension services disseminate research findings and updates through various media, including print materials, radio programs, mobile apps, and online platforms.

Community Engagement: Extension activities often involve community-based projects and collaboration with local organizations to enhance agricultural practices collectively (Yadav *et al.*, 2023).

Relationship between Extension and Researcher Providing Real-World Insights

Understanding Farmer's Needs: Extension agents work closely with farmers, gaining a deep understanding of their challenges, needs, and priorities. This information is invaluable for researchers, guiding them to focus on practical problems that require scientific solutions.

Identifying Research Gaps: By reporting on difficulties farmers face, extension services highlight gaps in current knowledge or technology, helping researchers identify areas for new studies or innovation.

Facilitating Field Trials and Research

Access to Field Sites: Extension services often facilitate access to farms and communities for conducting field trials and research. This collaboration ensures that experiments are carried out in diverse, real-world conditions rather than just controlled environments.

Data Collection Support: Extension agents can assist in collecting data for research, making it easier to gather large and representative samples.

Testing and Validating Research Findings

Feedback on Applicability: Extension services help test new technologies, practices, or crop varieties developed by researchers. The feedback they provide helps researchers to evaluate the practicality, benefits, and limitations of their innovations.

Adapting Innovations: Based on field feedback, researchers can adjust or refine their methods to ensure they are effective and easily adoptable by farmers.

Enhancing Research Impact

Wider Reach of Innovations: Extension agents play a key role in disseminating research findings to farmers, ensuring that scientific advancements reach those who can benefit most. This increases the visibility and real-world impact of the research.

Promoting Adoption: Extension services use com-

munication strategies and training programs to encourage the adoption of new practices, amplifying the benefits of research.

Enabling Participatory Research

Farmer-Researcher Collaboration: Through extension, researchers can engage in participatory research, where farmers are involved in the research process. This collaboration leads to solutions that are more relevant and practical, as farmers provide insights and suggestions during the development phase.

Co-Creation of Knowledge: Researchers and extension agents can work together with farmers to co-create knowledge, blending scientific understanding with traditional practices to develop holistic and sustainable solutions.

Providing Evidence for Policy Recommendations

Policy-Relevant Data: The data collected through extension activities can be used to support research-based policy recommendations. Researchers can use evidence gathered by extension agents to advocate for changes that benefit the agricultural sector.

Keeping Researchers Updated on Trends

Emerging Challenges: Extension agents often observe new challenges, such as emerging pest outbreaks, disease patterns, or shifts in market demands. They can alert researchers, enabling timely research and intervention.

Understanding Socio-economic Factors: Extension services provide insights into the socio-economic conditions of farming communities, which can influence research directions and ensure solutions

are economically viable for farmers.

Facilitating Communication between Stakeholders

Building Networks: Extension services help researchers connect with farmers, agricultural organizations, policymakers, and other stakeholders. This network is crucial for collaborative projects and the successful implementation of research findings.

Feedback Loops: Extension creates a feedback loop where farmers' experiences with new practices or technologies are communicated back to researchers, fostering continuous improvement and innovation. (Robert Chambers, 1983)

Discussion

The relationship between agricultural extension and researchers is crucial for advancing agricultural innovation and improving farming practices. This relationship ensures that scientific knowledge generated by researchers is effectively communicated to farmers and that farmers' needs and challenges inform future research priorities. Agricultural extension is essential for improving food security, enhancing rural livelihoods, and promoting sustainable farming practices. Extension workers play a critical role in bridging this gap. By working closely with farmers, they provide training, advice, and support to help implement research-based practices. They also gather feedback from the field, which researchers can use to refine and improve their innovations. This continuous feedback loop ensures that agricultural methods are not only scientifically sound but also practical and relevant to

real-world conditions. As a result, farmers can adopt techniques that maximize the efficient use of resources, such as water-saving irrigation systems, soil health management, integrated pest control, and climate-smart practices. This leads to reduced environmental impact, preservation of natural resources, and long-term agricultural sustainability. Overall, the strong partnership between extension workers and researchers ensures that the agricultural sector advances in a way that supports both productivity and environmental stewardship.

Conclusion

When extension workers and researchers work hand in hand, it creates a powerful synergy that promotes sustainable agriculture. This collaboration ensures that scientific research is translated into practical, actionable solutions that farmers can implement effectively. Researchers generate new knowledge, technologies, and methods aimed at enhancing agricultural productivity and resource efficiency. However, without proper dissemination and adaptation, these innovations may not reach the farmers who need them most.

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Management of Powdery Mildew of Apple

Arun Kumar and A. K. Verma

Introduction

Powdery mildew is a common fungal disease that affects a wide range of plants, including apple (*Malus domestica*). It is caused by the fungus *Podosphaera leucotricha*, which significantly impacts apple production by reducing fruit yield, quality, and overall tree vigor. The disease is particularly problematic in regions with warm, dry climates interspersed with high humidity.

Causal Organism

Scientific name: *Podosphaera leucotricha*

Classification

- ✓ Kingdom: Fungi
- ✓ Phylum: Ascomycota
- ✓ Class: Leotiomycetes
- ✓ Order: Erysiphales
- ✓ Family: Erysiphaceae

This fungus is an obligate parasite, meaning it requires living host tissue to survive and reproduce.

Symptoms

Leaves: Young leaves develop a white or grayish powdery coating, especially on the underside. Affected leaves may curl, twist, and become distorted.

Shoots: Infected shoots are stunted and may die back, especially at the growing tips.



Flowers: Infected blossoms may be covered with mildew and may fail to set fruit.

Fruits: Fruit infection is less common but can cause russetting or a net-like pattern on the surface, reducing market quality.

Disease Cycle

- ✓ *P. leucotricha* overwinters in dormant buds infected during the previous growing season.
- ✓ In spring, the fungus becomes active as buds break dormancy, spreading spores (conidia) to young shoots and leaves.
- ✓ The disease spreads rapidly under favorable conditions, primarily through wind-borne spores.
- ✓ Warm days and cool nights with high humidity (but not free moisture) favor the development of the disease.
- ✓ Unlike many fungal diseases, powdery mildew does not require free water for infection.



Favorable Conditions

- ✓ Moderate temperatures (18-25°C)
- ✓ High relative humidity (but not leaf wetness)
- ✓ Dense canopies with poor air circulation

Economic Importance

- ✓ Reduces photosynthetic capacity of leaves.

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- ✓ Causes poor fruit set due to blossom infection.
- ✓ Affects fruit quality and marketability.
- ✓ Reduces tree vigor and productivity over time.

Management Strategies

Cultural Control

Sanitation: Remove and destroy infected shoots and buds during winter pruning.

Airflow Management: Prune to open the canopy and improve air circulation.

Avoid Dense Planting: Maintain recommended spacing between trees.

Irrigation Management: Avoid overhead irrigation which can increase humidity.

Resistant Varieties

- ✓ Use cultivars with moderate to high resistance to powdery mildew where possible.
- ✓ Avoid highly susceptible varieties in areas with a history of the disease.

Chemical Control

Preventive Sprays: Apply fungicides at critical growth stages (e.g., pink bud, petal fall, early fruit development).

Fungicides Used

- ✓ Sulfur (organic and preventive)
- ✓ Myclobutanil
- ✓ Trifloxystrobin
- ✓ Potassium bicarbonate

Spray Intervals: 7-14 days depending on disease pressure and weather conditions. Rotate fungicide classes to delay resistance development.

Biological Control

- ✓ Products containing *Ampelomyces quisqualis* (a

mycoparasitic fungus) can help manage powdery mildew populations.

- ✓ Neem oil and other plant-based products may suppress early infections.

Integrated Disease Management (IDM)

- ✓ Combine cultural practices, resistant varieties, timely fungicide application, and monitoring.
- ✓ Use weather-based models to predict infection risk and optimize spray schedules.
- ✓ Regular scouting and record-keeping can aid in early detection and informed decision-making.

Conclusion

Powdery mildew of apple is a persistent and economically important disease that requires careful management. By integrating multiple control strategies including cultural, chemical and biological measures apple growers can effectively reduce disease impact and sustain high-quality production. Ongoing monitoring, early intervention, and use of resistant cultivars remain key to long-term success in managing powdery mildew in apple orchards.

Management of Purple Blotch of Onion

Chandan Kumar and A. K. Verma

Introduction

Purple blotch is a serious foliar disease of onion (*Allium cepa*), caused by the fungal pathogen *Alternaria porri*. The disease affects leaves, seed stalks, and bulbs, leading to significant yield losses and quality deterioration in both seed and bulb crops. It is prevalent in regions with warm, humid conditions and can cause up to 60% crop loss under severe infestations.

Causal Organism

Pathogen: *Alternaria porri*

Classification

- ✓ Kingdom: Fungi
- ✓ Phylum: Ascomycota
- ✓ Class: Dothideomycetes
- ✓ Order: Pleosporales
- ✓ Family: Pleosporaceae
- ✓ Genus: *Alternaria*

Alternaria porri produces characteristic pigmented spores (conidia) that are spread by wind, rain splash, or irrigation water.

Symptoms

Initial Lesions: Small, water-soaked, sunken lesions appear on older leaves.



Progression: Lesions enlarge into elliptical to elongated spots with purple centers and yellow halos.

Advanced Stages

- ✓ Lesions coalesce, leading to girdling and collapse of leaves.
- ✓ In seed crops, inflorescences and seed stalks may also be infected.
- ✓ Under high humidity, concentric rings with a target-like appearance develop.

Yield Impact: Reduced bulb size, delayed maturity, and poor storage quality.

Disease Cycle

- ✓ The fungus survives in infected plant debris, soil, and as spores on volunteer plants.
- ✓ Primary infection occurs through conidia under favorable weather conditions.
- ✓ Secondary spread is rapid via air-borne conidia, particularly in wet, humid environments.
- ✓ Long periods of leaf wetness (≥ 12 hours) and temperatures between 20-30°C favor disease development.



Favorable Conditions

- ✓ Relative humidity above 85%
- ✓ Leaf wetness due to dew, rain, or overhead irrigation
- ✓ Warm temperatures (25-30°C)
- ✓ Dense canopy and poor air circulation

Economic Importance

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- ✓ Reduces photosynthesis due to leaf blight.
- ✓ Leads to premature senescence and poor bulb formation.
- ✓ Causes up to 30-60% yield loss in severe outbreaks.
- ✓ Affects both bulb and seed quality and storability.

Management Strategies

Cultural Practices

Crop Rotation: Avoid planting onions in the same field consecutively; follow a 2-3 year rotation.

Sanitation: Remove and destroy infected crop debris after harvest.

Field Hygiene: Weed control and removal of volunteer onion plants to reduce inoculum.

Irrigation Management: Avoid overhead irrigation; irrigate in the morning to allow foliage to dry quickly.

Plant Spacing: Maintain adequate spacing for good air movement and reduced humidity.

Resistant Varieties

- ✓ Use moderately resistant or tolerant cultivars where available (e.g., 'Arka Kalyan', 'Arka Niketan').
- ✓ Breeding programs continue to develop better resistant lines.

Chemical Control

Fungicide Applications

- ✓ Mancozeb (0.2%)
- ✓ Chlorothalonil (0.2%)
- ✓ Propiconazole (0.1%)
- ✓ Azoxystrobin or Tebuconazole (as per label

recommendations)

Spray Schedule

- ✓ Begin at first sign of disease.
- ✓ Repeat every 10-14 days depending on weather and disease pressure.

Fungicide Rotation: Use different modes of action to prevent resistance.

Biological Control

- ✓ Use of biofungicides like *Trichoderma harzianum* or *Pseudomonas fluorescens* may help suppress initial infections.
- ✓ Plant extracts such as neem oil may also offer protective effects.

Integrated Disease Management (IDM)

- ✓ Combine cultural practices, timely fungicide applications, and resistant cultivars.
- ✓ Monitor weather forecasts to anticipate disease outbreaks and apply preventive measures.
- ✓ Use disease forecasting tools if available to optimize spray timing.

Conclusion

Purple blotch of onion, caused by *Alternaria porri*, is a destructive disease that affects both bulb and seed production. An integrated approach involving good cultural practices, resistant varieties, biological methods, and timely chemical control is essential for effective management. With proper monitoring and early intervention, significant losses can be prevented, ensuring better yields and improved crop quality.

Innovative Solutions for Sustainable Crop Production and Soil Restoration

Abhinav Sandilya, N. K. Sankhyan, Subhash Kumar and Prikxit

Abstract

The rapidly growing global population, projected to exceed 10 billion by 2050, is placing immense pressure on agricultural systems to meet rising food demands with limited land resources. Traditional farming practices, characterized by intensive monoculture and heavy chemical use, have led to significant soil degradation, threatening long-term agricultural productivity. Therefore, achieving sustainable food production requires innovative approaches that enhance crop yields while preserving environmental health. This study discusses various sustainable crop production and soil restoration strategies, including conservation agriculture, contour farming, rainwater harvesting, laser land leveling, balanced fertilizer use, site-specific nutrient management, precision farming, artificial intelligence, sensors, drones, vertical farming, agricultural biotechnology, bioremediation, and phytoremediation. Research has shown that integrating these advanced techniques can improve water use efficiency, optimize nutrient management, rehabilitate degraded soils, and increase agricultural output sustainably. Adopting such multifaceted practices is essential for maintaining soil health, ensuring food security, and promoting environmental sustainability for future generations.

Introduction

The rapid expansion of the global human population, expected to surpass 10 billion by 2050, presents profound challenges for agricultural systems (FAO, 2023). Increasing demands for food, fiber, and bioenergy exert significant pressure on finite land and water resources. Traditional agricultural practices, often emphasizing short-term yield maximization through intensive monocropping and chemical inputs, have led to severe degradation

of soil quality. Symptoms such as the loss of organic matter, erosion, nutrient depletion, soil compaction, and contamination have become widespread, affecting more than 33% of the world's soil. Sustainable agriculture, therefore, is not a mere choice but a necessity. Ensuring food security for future generations requires rethinking and redesigning agricultural systems with a strong focus on sustainability, resilience, and ecological balance. Innovative solutions, combining traditional knowledge with

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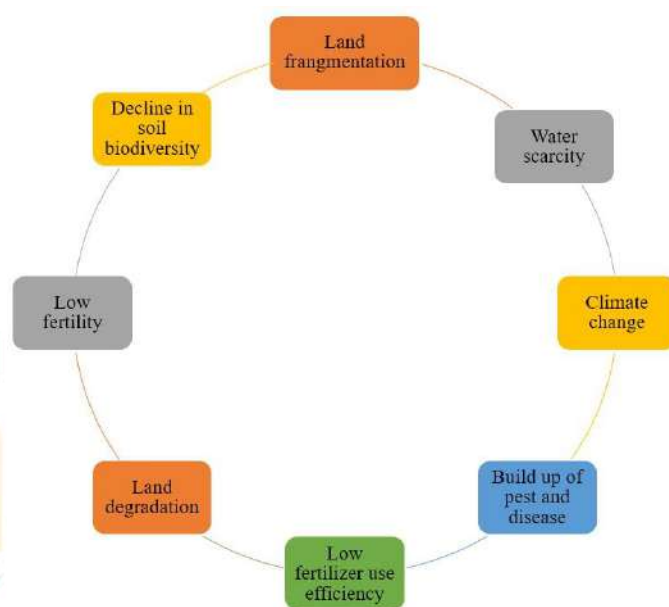
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modern technologies, offer promising pathways for achieving this goal. This article explores key strategies and technologies such as conservation agriculture, contour farming, rainwater harvesting, laser land leveling, site-specific nutrient management, artificial intelligence, phytoremediation, bioremediation, and agricultural biotechnology.

Challenges in Sustainable Agriculture and Soil Health

Modern agriculture faces a complex set of challenges, many of which are interconnected (Fig. 1). Continuous intensive cultivation, excessive chemical inputs, and poor land management practices have severely degraded soil health worldwide. This degradation is characterized by reduced soil fertility, weakened structure, lower water retention capacity, and diminished biological activity. Climate change further compounds these issues by intensifying water scarcity, making efficient water use in agriculture increasingly critical. Traditional irrigation methods often result in significant water wastage and contribute to soil salinization, reducing agricultural productivity over time. Additionally, the imbalanced application of fertilizers leads to nutrient runoff, environmental pollution, and inefficient nutrient utilization, further compromising soil productivity and ecosystem health. The growing frequency of extreme weather events, temperature variability, and shifting rainfall patterns introduces new risks to both crop yields and soil sustainability (khan *et al.*, 2022). Moreover, the rapid expansion of urban areas continues to shrink

the amount of arable land available, thereby heightening the urgency for sustainable intensification of agricultural systems. Addressing these complex challenges requires an integrated approach that combines innovative technologies with sustainable agricultural practices, ensuring both productivity and environmental stewardship.



Emerging Technologies and Sustainable Practices

Conservation Agriculture: Conservation agriculture (CA) is a sustainable farming approach based on three core principles: minimal soil disturbance through no-till practices, permanent soil cover with cover crops or crop residues, and diversified crop rotations. By minimizing soil disturbance, CA reduces erosion and preserves soil structure, while continuous organic cover enhances soil microbial activity and organic matter levels. Diversified crop rotations help break pest and disease cycles and improve soil fertility. Collectively, these practices lead to better water retention, reduced evaporation losses, lower input costs, and contribute significantly

to carbon sequestration, helping mitigate climate change impacts. CA thus plays a crucial role in restoring degraded lands and building resilient agricultural systems.

Contour farming: Contour farming involves plowing and planting crops along the natural contours of the land instead of following straight up-and-down slope lines. This method significantly slows water runoff, allowing more water to infiltrate the soil and thereby reducing soil erosion. By retaining more soil moisture, contour farming improves soil fertility and enhances crop yields, especially in sloping terrains and mountainous regions. In areas highly prone to erosion, integrating contour farming with strip cropping techniques offers additional advantages, making land use more sustainable and productive.

Rainwater Harvesting: Rainwater harvesting focuses on collecting and storing rainwater for agricultural use, particularly valuable in arid and semi-arid regions facing frequent droughts. By capturing rainwater through farm ponds, check dams, and percolation tanks, farmers can maintain irrigation during dry spells and reduce reliance on over-extracted groundwater resources. Rainwater harvesting also plays a key role in minimizing soil erosion by controlling surface runoff, thus helping to sustain soil health over time and increasing the reliability of rainfed agriculture.

Laser land levelling: Laser land leveling is a precision agriculture technology that uses laser-guided equipment to level fields uniformly. Uniform

land slopes ensure that irrigation water spreads evenly across the field, significantly improving water-use efficiency by 20-30%. Fields leveled with laser technology require less irrigation time and labor and result in better seed establishment and more uniform crop growth. Successful large-scale adoption in regions like Punjab and Haryana has demonstrated increased crop yields, particularly in rice and wheat, while conserving substantial amounts of water (Aryal *et al.*, 2015).

Site specific nutrient management: Site-specific nutrient management customizes fertilizer application based on the specific nutrient needs of different fields and crops, informed by soil testing and real-time monitoring technologies. Tailoring fertilizer use improves nutrient uptake efficiency and reduces environmental pollution caused by nutrient runoff (Kumar *et al.*, 2022). The use of GPS-based soil mapping, sensors, and decision-support systems enables farmers to apply the right amount of nutrients at the right time and place, resulting in higher crop yields, better soil health, and more profitable farming operations.

Artificial Intelligence: Artificial intelligence is transforming agriculture by enabling smarter, data-driven decisions across farm operations. AI algorithms analyze data from satellite imagery, soil sensors, and weather models to optimize irrigation, fertilization, pest management and harvesting schedules. Predictive analytics helps farmers anticipate weather patterns and potential pest outbreaks, allowing proactive and timely interventions. Automation

technologies, including drones and robotic equipment, further enhance operational efficiency, reducing labor costs and supporting sustainable intensification of crop production (Ghobari and Mohammad, 2011).

Phytoremediation: Phytoremediation is an environmentally friendly method that uses certain plants to remove, degrade, or immobilize pollutants from contaminated soils. Plants known as hyperaccumulators absorb heavy metals and toxic substances such as lead, arsenic, and cadmium, helping to detoxify the soil naturally. Unlike chemical or mechanical remediation methods, phytoremediation is cost-effective and preserves soil structure and fertility. This technique is particularly valuable for restoring agricultural lands affected by industrial pollution, making them productive once again (Ravi *et al.*, 2015).

Bioremediation: Bioremediation employs microorganisms to degrade or neutralize harmful pollutants in the soil, such as pesticides, hydrocarbons, and organic contaminants. Microbial consortia, composed of specially selected bacterial and fungal species, break down complex toxic compounds into harmless products. This biological process not only detoxifies the soil but also enhances microbial diversity, leading to improved soil fertility and health. Bioremediation thus represents a sustainable solution for rehabilitating contaminated lands and expanding usable agricultural areas.

Agricultural Biotechnology: Agricultural biotechnology applies advanced techniques like genetic

engineering, molecular markers, and tissue culture to develop crop varieties with desirable traits. Biotechnological innovations have produced crops that are more resistant to pests, diseases, and environmental stresses such as drought and salinity. These crops also demonstrate improved nutrient-use efficiency and higher yields, reducing the need for chemical fertilizers and pesticides. Genetically modified crops like drought-tolerant maize and pest-resistant cotton exemplify how biotechnology can contribute to sustainable agriculture by enhancing productivity while minimizing the environmental footprint.

Integrating Technologies for Maximum Impact

While each of these technologies and practices offers significant benefits individually, their integration can lead to transformative impacts on agricultural sustainability:

- ✓ Combining conservation agriculture with AI-driven soil monitoring can optimize crop management practices.
- ✓ Using rainwater harvesting systems in contour farmed fields can further reduce erosion and water loss.
- ✓ Integrating site-specific nutrient management with precision land leveling and automated irrigation systems ensures efficient resource use.

Such integrated approaches foster resilient agricultural ecosystems that are more productive, sustainable, and climate-resilient.

Conclusion

Sustainable crop production and soil restoration are pivotal to meeting the food demands of an

ever-growing global population while protecting the environment. The transition from traditional practices to innovative, sustainable technologies is both an opportunity and a necessity. Conservation agriculture, contour farming, rainwater harvesting, laser land leveling, site-specific nutrient management, artificial intelligence applications, phytoremediation, bioremediation, and agricultural biotechnology collectively provide robust solutions to restore degraded soils and enhance agricultural productivity sustainably. However, the success of these technologies hinges on supportive policy frameworks, farmer education and capacity building, research and development investments and participatory approaches that involve stakeholders at every level. By adopting and integrating these innovative solutions, we can create resilient food systems that ensure long-term soil health, agricultural sustainability, and global food security.

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Innovative Water Management Technologies for Climate Resilience

Nishant Dhiman, N. K. Sankhyan, Navneet Jaryal and Prikxit

Abstract

Water is a critical resource underpinning life, agriculture and industry, yet it is increasingly threatened by overexploitation, pollution and climate change. This article examines the urgent need for climate resilient water technologies to address escalating water scarcity and quality challenges. It outlines major barriers to adoption including inefficient irrigation practices, groundwater depletion and climate variability. Key technological solutions are explored, such as smart irrigation systems using IoT and AI, advanced desalination methods like reverse osmosis and thermal distillation, and urban greywater recycling. The role of nature-based solutions including fog harvesting and mycofiltration is also highlighted for their sustainability and ecological relevance. The review emphasizes that integrating innovative technologies with policy support, public engagement, and traditional practices is essential for building adaptive capacity and securing long-term water sustainability. Through a multi-disciplinary approach that bridges science, technology, and governance, the path toward resilient water management systems becomes achievable and urgent.

Introduction

Water is an indispensable natural resource that underpins life, agricultural productivity, industrial processes, and the maintenance of ecosystems. However, the world is witnessing an intensifying water crisis, exacerbated by rapid population growth, urbanization, climate change, and unsustainable practices. According to the Food and Agriculture Organization (FAO, 2023), agriculture alone consumes approximately 70% of the world's freshwater, placing tremendous stress on available resources.

Moreover, NITI Aayog's 2019 report on India highlights that by 2030, the country's water demand will exceed supply by nearly twofold, posing significant threats to food security, economic development, and societal well-being. Addressing this crisis demands the adoption of innovative water management technologies that integrate scientific advancements with sustainable practices. This review discusses the need for climate-resilient water technologies, explores key innovations in agriculture and urban water management, examines nature-based solutions

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and offers insights into future prospects for sustainable water governance.

Barriers to Change: Challenges in Adopting Climate-Resilient Technologies

The sustainable management of freshwater resources is hindered by several critical challenges. Groundwater depletion has reached alarming levels in many regions, primarily due to unregulated extraction and inadequate recharge practices. Traditional irrigation methods, such as flood irrigation, result in significant water wastage through evaporation and runoff. Pollution from industrial effluents, agricultural chemicals, and domestic waste has further deteriorated the quality of available freshwater. Additionally, climate variability has introduced unpredictability in precipitation patterns, leading to frequent droughts and floods that disrupt agricultural cycles and urban water supplies. The urgency to adopt climate-resilient technologies stems from the necessity to conserve water, diversify water sources, reduce dependence on erratic weather patterns, ensure food security, and protect ecological integrity. By incorporating innovative solutions, societies can build adaptive capacity and resilience to withstand the multifaceted impacts of climate change.

Smart Water Management in Agriculture

Agriculture remains the primary consumer of freshwater globally. Therefore, innovations aimed at enhancing irrigation efficiency can significantly alleviate water stress. Traditional irrigation techniques are not only inefficient but also contribute

to soil degradation and nutrient loss. Recent advancements have introduced a range of smart water management technologies designed to optimize water use in farming systems. Software models like CROPWAT and the RZWQ model have revolutionized irrigation scheduling. CROPWAT, developed by the FAO, calculates crop water requirements based on climatic data, crop type, and soil conditions, thereby enabling precise irrigation planning. Similarly, the RZWQ model assists in managing the water quality within the root zone, ensuring optimal soil moisture and minimizing leaching losses. The integration of the Internet of Things (IoT) and Artificial Intelligence (AI) into agriculture has further enhanced precision irrigation. Soil moisture sensors, pressure sensors, humidity sensors, and leak detectors provide real-time data that inform automated irrigation systems. These technologies ensure that crops receive the exact amount of water they need, reducing wastage and improving yields. Field studies provide compelling evidence of the benefits of smart irrigation. For instance, a study conducted in Raipur, India, demonstrated that automated drip irrigation systems led to a 30% improvement in both water-use efficiency and cabbage crop yields (Ganjeer *et al.*, 2019). Furthermore, laser land leveling techniques have been widely adopted to achieve uniform field surfaces, resulting in up to 30% water savings and enhanced crop productivity, as observed in paddy cultivation projects in Vietnam.

Advanced Water Purification and Desalination

Technologies

As freshwater sources become increasingly strained, alternative water resources such as seawater and greywater are gaining prominence. Desalination technologies offer a viable solution for augmenting water supplies, particularly in arid and semi-arid regions. Reverse Osmosis (RO) remains the most widely utilized desalination technology. It operates by forcing saline water through a semi-permeable membrane under high pressure, effectively removing dissolved salts and impurities. RO plants have been instrumental in providing potable water in countries such as Israel, Saudi Arabia and Australia. Nevertheless, the energy-intensive nature of RO processes poses economic and environmental challenges. Thermal distillation, another desalination method, involves evaporating water and subsequently condensing the vapor to obtain freshwater. This process is particularly effective when coupled with waste heat from industrial activities, offering an energy-efficient alternative. In urban contexts, greywater recycling has emerged as a sustainable approach to reduce freshwater consumption. Greywater, comprising water from showers, sinks, and washing machines, can be treated through sedimentation tanks, biological disc filters, and lamella separators to produce water suitable for non-potable uses such as landscape irrigation and toilet flushing. Research conducted in Beijing, China (Zhang *et al.*, 2009), indicated that the adoption of greywater recycling systems in residential complexes reduced freshwater consumption by over 35%.

Biomimicry and Nature-Based Solutions

Nature offers exemplary models for efficient water management, inspiring a host of biomimicry-based innovations. One notable example is fog harvesting, inspired by desert beetles that possess micro-structured shells capable of collecting water droplets from fog. Scientists have replicated this mechanism to develop biomimetic materials designed for water collection in arid environments. Studies conducted in China (Jiang *et al.*, 2023) have shown that altering the curvature of the collection surfaces enhances the efficiency of fog trapping, offering a promising solution for water-scarce regions. Another nature-based approach is mycofiltration, which involves the use of fungi to purify contaminated water. *Lentinus squarrosulus*, a species of mushroom, has demonstrated remarkable potential in removing heavy metals and oil residues from wastewater generated by automobile workshops. In Port Harcourt, Nigeria, mycofiltration systems successfully treated polluted soil leachate, showcasing their applicability in industrial contexts (Nwogu *et al.*, 2021). Additionally, traditional water harvesting structures such as check dams, percolation ponds, and bio-sand filters continue to play a vital role in enhancing groundwater recharge and promoting sustainable agriculture in water-scarce regions.

Future Prospects

The future of water management lies in the integration of advanced technologies with sustainable practices and proactive policy interventions.

Emerging innovations include AI-driven water management systems that utilize predictive analytics to optimize irrigation schedules and urban water distribution networks. The development of smart cities with integrated water grids that promote recycling, rainwater harvesting, and efficient distribution represents a forward-thinking approach to urban water sustainability. Nano-enabled water purification technologies are also gaining traction, offering the potential to remove even microscopic pollutants from water sources. Furthermore, solar-powered desalination units are being explored as an energy-efficient method of producing freshwater in remote and off-grid communities. Policy frameworks must evolve to support these technological advancements. Incentivizing the adoption of precision irrigation systems, mandating greywater recycling in urban planning, and promoting international collaborations for knowledge-sharing are essential steps toward achieving water security. Public education and community engagement are equally critical to fostering a culture of water conservation and stewardship.

Conclusion

The global water crisis demands immediate and coordinated action. Innovative water management technologies provide powerful tools to address the challenges of water scarcity, pollution, and climate-induced variability. Through the adoption of smart irrigation systems, advanced desalination techniques, greywater recycling, and nature-based solutions, societies can build resilience against future

uncertainties. However, technology alone cannot solve the water crisis. Effective governance, supportive policies, capacity building, and active community participation are imperative to ensure the successful implementation and sustainability of these innovations. As emphasized by the FAO, science and technology are powerful drivers for transformative change in agriculture and water management. By embracing innovation, collaboration and sustainability, humanity can secure a future where water is preserved, respected, and equitably shared.

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Antimicrobial Potential and Screening of Phytochemical Compounds in *Lantana camara* Linn.

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Abstract

The antimicrobial activity of *Lantana Camara*. Linn, and its anti-microbial potential is well known to cure several diseases. Scientists and researchers from all over the world have extensively investigated the chemical makeup of every part of *Lantana camara* plant as well as their biological pharmacological properties in the last few decades. The qualitative analysis and phytochemical evaluation revealed the presence of flavanoids, triterpenoids and alkaloid. The presence of triterpenoids in *Lantana camara* may contribute to its antimicrobial activity. Phytochemicals exhibiting antimicrobial properties hold significant promise in controlling plant diseases. The application of antimicrobial phytochemicals in agriculture as a component of an Integrated Disease Management approach will help reduce the harmful after effects of synthetic chemicals.

Introduction

Certain circumstances exist in agriculture with respect to crop diseases. The primary causes of significant crop diseases and reductions in yield are bacteria and fungi. Synthetic pesticides are typically used by farmers as a rapid pest management solution to reduce diseases and preserve productivity. However, synthetic pesticide residues have a detrimental influence on biodiversity since they are extremely toxic and have been demonstrated to have harmful effects on plants that are not their intended target. Moreover, negligent and inconsistent application has led to the resurgence of disease and the development of resistant strains of pathogens. Therefore, a more effective pesticide that can control

plant diseases needs to be developed. Botanical insecticides derived from plants offer an eco-friendly and sustainable alternative to synthetic pesticides. Furthermore, the active chemicals found in these plants are biodegradable and pose a reduced risk to the environment. One of the most common weed plants in the world is *Lantana camara*.

It belongs to Verbanaceae family and found in many parts of Asia including India. The plant also exhibits a great variation in chemical constituents according to geographical regions and climate. The plant contains a variety of powerful phytochemicals that can be utilized for the control and protection against plant diseases, thus minimizing the excessive reliance on synthetic pesticides.

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The leaves of the plant contain many compounds that have medicinal and antimicrobial properties and also contain compounds such as Phenols, steroids, flavanoids and alkaloids. The phytochemical of leaf extract of *Lantana camara* have been reported to possess natural substances that may be toxic to many fungi and bacteria causing plant diseases. Thus this article will help us to understand how these plant products can be used as biocontrol agent and may be effective against many plant pathogens. It will provide basis for developing the plant products into useful pesticides that may be used to control soil pathogenic bacteria and fungi.



Table 1: Plant profile of *Lantana camara* Linn.

Botanical Name	<i>Lantana camara</i> L.
Common Name	Raimuniya, Wild sage
Plant Family	Verbenaceae
Plant Form	Shrub
Occurrence	Found in many parts of Asia including India (in sub-montane and montane zones).

Phytochemical Composition: The phytochemical composition of *Lantana camara* has been thoroughly researched over the past few decades. Different parts of *L. camara* are reported to possess essential oils,

phenolic compounds, flavanoids, carbohydrates, proteins, alkaloids, glucosides, phenyl ethanoid, oligosaccharides, quinine, saponins, steroids, triterpenes, sesquiterpenoids and tannin as major phytochemical groups.

Primarily the phytochemical group of compounds that are majorly responsible for the antimicrobial activity of *Lantana camara* Linn are:

Terpenoids: The essential oil derived from *L. camara* is rich in sesquiterpenes, including bicyclogermacrene (19.42%), isocaryophyllene (16.70%), valecene (12.94%), and germacrene D (12.34%). These compounds have demonstrated antibacterial effects against pathogens like *Escherichia coli* and *Staphylococcus aureus*.

Phenolic Compounds: The plant contains various phenolic compounds that possess antimicrobial properties. These compounds have the ability to impede microbial proliferation by interfering with cell membranes and deactivating microbial enzymes.

Tannins: Tannins have astringent properties and can inactivate microbial adhesions, enzymes, and cell envelope transport proteins, thereby exhibiting antimicrobial effects.

Saponins: Saponins are known for their membranolytic properties, which contribute to their antibacterial activity. They have the potential to disrupt microbial cell membranes, resulting in cell death.

Alkaloids: Alkaloids such as atropine and scopolamine have been isolated from the leaves and flowers of *L. camara*. These compounds exhibit

inhibitory effects against *Staphylococcus aureus* and *Escherichia coli*.

Antibacterial activity: Different varieties of *L. camara* plants' leaves and flowers were reported for antibacterial activity. Three different solvent extract of leaves and flowers of four different varieties of *L. camara* exhibited significant antibacterial activity *E. coli*, *Bacillus subtilis* and *P. aeruginosa* whereas poor antibacterial activity against *Staphylococcus aureus*. Ethanolic extracts of *L. camara* leaves and roots were reported for antibacterial activity. The in vitro antibacterial activity was performed by microdilution method. The extracts exhibited antimicrobial activity against *Staphylococcus aureus*, *Proteus vulgaris*, *Pseudomonas aeruginosa*, *Vibrio cholerae*, *Escherichia coli* and two multiresistant strains *E. coli* and *S. aureus*. Methanolic extracts of different parts of *Lantana camara* were screened for antimicrobial activity against 10 bacteria and 5 fungi by disk diffusion method and broth microdilution method. The leaf extract of *Lantana camara* exhibited the most significant activity against the Gram-positive bacterium *Bacillus cereus* and the Gram-negative bacterium *Salmonella typhi*.

Antifungal Activity: *Lantana camara* exhibited antifungal properties against *Alternaria* sp., a pathogen responsible for various plant diseases, particularly in vegetable crops. The antifungal efficacy assessed using the food poison plate method at three distinct concentrations of extract, namely 10 mg ml⁻¹, 15 mg ml⁻¹ and 20 mg ml⁻¹, demonstrated that *Lantana camara* showed considerable antifungal

activity against *Alternaria* sp. The extract of *Lantana camara*, derived from ethanol and hot water, exhibited antifungal properties against wood-decaying white and brown rot fungi. Both extracts demonstrated effective antifungal properties against white and brown rot fungi; however, the ethanol extract showed significant potency even at a very low concentration of 0.01%.

Conclusion

The phytochemical analysis of *Lantana camara* leaf extracts showed the presence of different secondary metabolites, like alkaloids, phenols, flavonoids, glycosides, tannins and terpenoids. Presence of these compounds have demonstrated antimicrobial activity against various plant pathogens. The exploitation of these compounds as biopesticide can reduce dependence on chemical pesticides whose overuse have detrimental effect on soil and plant health.

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Microgreens: A Superfood

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In the past decade, especially during and post-COVID-19, there has been a significant shift toward consuming fresh, healthy, and functional foods like microgreens and sprouted seeds. These tiny, nutrient-dense plants are becoming increasingly popular due to their exceptional nutritional value and appeal to consumers seeking novelty, flavour and health benefits. Microgreens, often referred to as “vegetable confetti” are young seedlings harvested when their cotyledons (seed leaves) are fully developed, and the first true leaves are emerging. Despite their small size, microgreens are packed with high concentrations of vitamins, minerals, antioxidants and other bioactive compounds, making them a superfood. Besides their nutritional benefits, microgreens are prized for their intense sensory qualities, including flavor, texture, aroma, and vibrant colors. They are commonly used in gourmet cuisine to garnish salads, soups, and sandwiches. The growing demand for these functional foods can be attributed to their versatility and rapid growth, as they can be harvested in just 7-21 days after germination. Additionally, microgreens require minimal space and resources to grow, making them an ideal option for home gardeners and commercial producers alike. They are particularly

popular among vegans and health-conscious individuals who prefer raw, nutrient-enriched foods. As microgreens continue to gain recognition, they are poised to revolutionize the way we approach healthy eating, offering a sustainable and accessible source of essential nutrients.

Need for microgreens: The need for microgreens in modern agriculture has become increasingly evident due to several factors. Urbanization, coupled with shifting eating patterns, has made it harder to access fresh, pesticide-free vegetables. Long food supply chains, essential for urban populations, limit access to fresh produce with short shelf lives. Consequently, lifestyle-related diseases and nutritional deficiencies have risen, largely due to the increased consumption of processed foods. Microgreens offer a practical solution to these challenges. They are easy to grow in small spaces, making them ideal for urban environments and home gardens. Packed with essential vitamins, minerals and antioxidants, microgreens provide a rich source of nutrients that can address nutritional gaps. Their rapid growth and minimal resource requirements make them a sustainable option for boosting food security and improving overall health. As a result, microgreens are becoming a crucial component of modern agricu-

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lture, offering fresh, nutrient- dense food with a minimal environmental footprint.

Different types of Microgreens: Microgreens are



produced both on small and large scales, often alongside commercial vegetable and edible

flower production. They are cultivated from a variety of vegetables and herbs from families like Amaranthaceae, Apiaceae, Brassicaceae, Leguminosae, Apiaceae, Asteraceae, Boraginaceae, Convolvulaceae, Cucurbitaceae, Malvaceae, Poaceae, Portulacaceae and more. Common varieties include amaranth, beet, parsley, radish, lettuce, cilantro, cucumber, carrot, cauliflower, broccoli, onion, garlic, coriander, fenugreek, pea, lentil, chickpea, bean and even cereals like corn and wheat. Microgreens are selected for their appearance, taste, texture, and nutritional value, with flavors ranging from bitter to mild, spicy, or sour. Species are chosen based on factors such as seed quality, germination capacity, hygiene, low cost and availability throughout the year. Characteristics like color, texture, and shelf-life are also important in species selection. Microgreens are valued for their diversity in phytochemical compositions and their potential to add variety and nutrition to diets.

Procedure for Microgreen Production

Prepare the media: Begin by selecting a tray or punnet and punch a few holes in the bottom for drainage. Fill the tray with a seed-sowing medium like cocopeat, about 1-2 inches deep. Pat it down to

remove any air pockets. Then, lightly spray the surface with water to moisten the cocopeat, ensuring an even consistency.

Sowing of seeds: Evenly sprinkle your chosen microgreens seeds across the moist surface of the cocopeat. If it's difficult to spread them evenly, just do your best. The water sprayed in Step 1 will help the seeds adhere to the surface.

Covering of seeds: Gently cover the seeds with a layer of cocopeat, about half an inch thick. Press the cocopeat down to ensure there are no air pockets.

Watering the container: Thoroughly mist the surface with water using a spray can. Then, cover the tray with a wet towel or newspaper to maintain moisture. This helps the seeds germinate properly.

After sowing, place the tray in a well-ventilated spot away from direct sunlight. Keep the cocopeat moist, spraying with water as needed. In 3-4 days, you'll see small roots emerging. Continue to maintain moisture, and soon you'll see the seedlings pushing through the top layer of cocopeat. In 7-14 days, your microgreens will be ready to harvest.

Health benefits

Microgreens offer numerous health benefits due to their rich concentration of essential nutrients. These tiny greens are packed with vitamins, minerals, antioxidants, and bioactive compounds that can contribute to overall health and well-being. Some key health benefits include:

High Nutrient Density: Microgreens are often more nutrient-dense than their mature counterparts, providing high levels of vitamins like A, C, E, and

K, as well as essential minerals such as calcium, magnesium, and potassium.

Antioxidant Properties: Many microgreens are rich in antioxidants like flavonoids and carotenoids, which help protect cells from oxidative stress and may reduce the risk of chronic diseases like cancer and heart disease.

Improved Digestion: The fiber content in microgreens promotes healthy digestion and supports gut health by aiding in regular bowel movements.

Anti-inflammatory Effects: Some microgreens, such as radish and broccoli, contain compounds that may help reduce inflammation in the body, potentially lowering the risk of inflammatory diseases.

Boosting Immunity: The high levels of vitamins, particularly vitamin C, found in microgreens can help strengthen the immune system, making the body more resilient to infections.

Weight Management: Microgreens are low in calories and high in nutrients, making them a great addition to a weight-conscious diet while providing essential vitamins and minerals without extra calories.

Future Prospects

Microgreens are a promising, nutrient-dense food source, rich in essential vitamins, minerals, and bioactive compounds like antioxidants and polyphenols. These functional foods offer numerous health benefits, including antioxidant, anti-inflammatory, and anti-diabetic effects, which may help prevent or manage chronic diseases.

Their quick growth cycle and minimal resource needs make them an ideal crop for urban and small-scale farming, providing a sustainable, profitable farming option. However, challenges remain in optimizing production techniques, storage, and ensuring microbial safety to prevent foodborne diseases. Further research is needed to fully understand the health benefits and bioactive profiles of different microgreens, as well as to refine growing and harvesting methods. With the right investment and planning, microgreens farming can not only contribute to healthier populations but also offer a reliable income for farmers, enhancing both nutrition and food security in urban and rural areas.

Unlocking the Potential of Lemongrass: Value-Added Products for Home Entrepreneurs

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Abstract

This article provides a comprehensive exploration of *Cymbopogon citratus* (lemongrass), highlighting its potential as a multifunctional crop with significant applications in health, wellness, environmental sustainability, and entrepreneurship. Drawing from traditional knowledge and scientific studies, it outlines the plant's bioactive compounds and their evidence-based therapeutic benefits, including antimicrobial, anti-inflammatory, digestive, and anxiolytic properties. Beyond its medicinal relevance, the article focuses on how lemongrass can be transformed into a range of value-added products such as essential oils, teas, skincare formulations, insect repellents, and culinary items making it an ideal candidate for small-scale home-based enterprises. Practical insights are also provided on sustainable cultivation practices, environmental contributions like soil conservation and carbon sequestration, and integration into regenerative agricultural models. This work aims to serve as a resource for students, researchers, policy-makers, and entrepreneurs seeking holistic perspectives on lemongrass cultivation, commercialization, and ecological impact. By bridging traditional uses with modern applications, the article positions lemongrass as a catalyst for grassroots innovation and sustainable development.

Introduction

Lemongrass, popularly known as citronella grass, is a plant species that belongs to the family Poaceae and to the genus *Cymbopogon*. Lemongrass (*Cymbopogon citratus*), with its distinctive citrusy aroma and versatile applications, has been a staple in tropical cuisines and traditional medicine for centuries. It is more than just a fragrant herb used in Asian cooking. With its numerous medicinal, cosmetic, kitchen, and culinary benefits, lemongrass presents a lucrative opportunity for home entrepreneurs

looking to create value-added products. Its essential oil, dried leaves, and extracts are highly sought after in various industries, from wellness to food and beverages. These are perennial aromatic grasses with a distinctive lemon-like odor that grow in dense clumps and can reach heights up to 3 feet. The name 'lemon' is derived from the citral monoterpenes it contains. Lemongrass is rich in essential compounds like citral and geraniol, making it a potent antibacterial, antifungal, and anti-inflammatory agent. It is renowned for its digestive

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benefits, stress-relief properties, and natural insect-repelling abilities. With the growing consumer demand for organic and natural products, lemongrass-based offerings are gaining considerable traction in the market.

Traditional importance: In the continents of Asia, South America, and Africa, the leaves have traditionally been utilized as tea or decoction. These leaves contain essential bioactive compounds that determine the plant's various ethno-medicinal properties. Additionally, they are employed as deodorants in numerous products such as perfume, local soaps, candles, and other insect repellents. Moreover, in certain regions of Asia and African countries, they have been employed as snake and reptile repellents (Oladeji *et al.*, 2020).

Active Compounds

The plant's medicinal properties stem from its rich phytochemical profile.

Citral (Neral and Geranial): The primary component (65-85% of essential oil), responsible for most medicinal properties

Myrcene: Possesses analgesic and anti-inflammatory effects.

Limonene: Shows anticancer and antioxidant properties.

Citronellal: Provides the mosquito-repelling properties.

Geraniol: Exhibits antimicrobial effects.

Flavonoids and Phenolic Compounds: Contribute to antioxidant activities.

Evidence-Based Medicinal Benefits

Anti-inflammatory Properties: Multiple studies have demonstrated lemongrass's ability to reduce inflammation. A 2018 study published in the Journal of Ethnopharmacology found that citral significantly decreased inflammatory markers in laboratory models of inflammation. This supports its traditional use for treating arthritis and inflammatory conditions. Research by Sforcin *et al.* (2009) showed that lemongrass extract inhibited the production of pro-inflammatory cytokines, suggesting a molecular basis for its anti-inflammatory effects.

Antimicrobial Activity

Lemongrass essential oil has shown broad-spectrum antimicrobial activity against numerous pathogens:

Bacterial Infections: Research by Naik *et al.* (2010) demonstrated effectiveness against *Staphylococcus aureus*, *Bacillus subtilis*, *Escherichia coli*, and *Pseudomonas aeruginosa* including some antibiotic-resistant strains.

Fungal Infections: Studies by Hammer *et al.* (2012) showed potent activity against *Candida albicans* and dermatophytes responsible for skin infections.

Viral Properties: Limited studies suggest potential activity against certain viral infections, though this area requires further research.

Anxiety and Stress Reduction

A clinical trial published in the Journal of Alternative and Complementary Medicine (2015) found that lemongrass tea consumption significantly reduced anxiety symptoms and improved sleep quality in participants with mild to moderate anxiety

disorders. Another study by Costa *et al.* (2011) confirmed that lemongrass essential oil had anxiolytic effects comparable to diazepam in experimental models, without the sedative side effects.

Digestive Health

Research supports lemongrass's traditional role in digestive wellness:

- ✓ A 2012 clinical study in the International Journal of Gastroenterology showed that lemongrass infusion reduced symptoms of irritable bowel syndrome by 62% compared to placebo.
- ✓ Laboratory studies have confirmed its ability to protect the gastric mucosa against damage from NSAIDs and alcohol, potentially helping prevent ulcers.
- ✓ Research indicates that lemongrass stimulates digestive enzyme production and peristalsis, improving overall digestive function.

Cardiovascular Benefits

Emerging research points to potential heart health benefits:

- ✓ A study published in the Journal of Advanced Research (2014) found that regular consumption of lemongrass tea was associated with moderate reductions in blood pressure and cholesterol levels.
- ✓ Research by Devi *et al.* (2012) demonstrated that lemongrass extract reduced platelet aggregation, potentially helping prevent blood clots.

Cancer-Fighting Potential

Several preclinical studies have investigated lemongrass's anticancer properties:

- ✓ Research published in Food and Chemical Toxicology demonstrated that citral induced apoptosis (programmed cell death) in several human cancer cell lines, including breast cancer, colon cancer, and neuroblastoma cells.
- ✓ A 2017 study in the Journal of Medicinal Food showed that lemongrass extract inhibited the growth and spread of prostate cancer cells in laboratory models.

It's important to note that most cancer research remains at the preclinical stage, and clinical trials are needed to confirm therapeutic potential in humans.

Value-Added Products from Lemongrass

Home entrepreneurs can explore several innovative products using lemongrass:

Lemongrass Essential Oil: Lemongrass essential oil is extracted through steam distillation and is widely used in aromatherapy, skincare, and natural cleaning products. It has antibacterial properties that make it an excellent ingredient for hand sanitizers and household disinfectants.

Herbal Teas and Infusions: Dried lemongrass leaves make refreshing herbal teas, often blended with ginger, tulsi, or green tea. These infusions are known for their detoxifying effects and digestive benefits, making them a great addition to the wellness industry.

Lemongrass-Based Skincare Products: With its antimicrobial and soothing properties, lemongrass is used in soaps, lotions, and face mists. It helps reduce acne, control excess oil and refresh the skin naturally.

Insect Repellents: Lemongrass oil is a natural insect repellent, commonly used in mosquito sprays, candles and diffusers. Given the increasing awareness of harmful chemicals in synthetic repellents, eco-friendly alternatives are in high demand.

Lemongrass-Flavored Culinary Products: Lemongrass can be infused into syrups, jams, and sauces for gourmet culinary applications. It adds a citrusy zest to foods and beverages, making it an excellent ingredient for exotic flavor blends.

Business and Market Potential

The global demand for natural and organic products is rising, and lemongrass-based goods fit well into this trend. Entrepreneurs can start small by selling locally or online, targeting niche markets such as wellness enthusiasts, organic food lovers, and sustainable living advocates. To stand out in the market, branding and proper packaging play a crucial role. Sustainable packaging, informative labeling, and storytelling about the benefits of lemongrass can help build consumer trust and loyalty.

Beyond the Kitchen

Lemongrass has transcended culinary uses to become a popular ingredient in:

Aromatherapy: The essential oil is used in diffusers and massage oils for its calming and mood-enhancing properties.

Personal Care Products: Its fresh scent makes it a popular addition to soaps, shampoos, and lotions.

Insect Repellent: The citronella content in lemongrass serves as a natural deterrent against mosquitoes and other insects.

Ornamental Gardening: With its attractive form and pest-repelling qualities, lemongrass is increasingly used in landscaping.

Growing Your Own

- ✓ One of the appealing aspects of lemongrass is how easily it can be cultivated. In tropical and subtropical climates, it grows readily outdoors, while in cooler regions, it can be grown in containers and brought indoors during winter months. With minimal care requirements and resistance to most pests, it's an excellent choice for home gardeners.
- ✓ From enhancing culinary creations to offering numerous health benefits, lemongrass continues to prove itself as more than just a fragrant herb. Its versatility across different applications makes it a valuable plant worth incorporating into our daily lives.

Environmental Impact and Sustainability

As interest in lemongrass grows globally, understanding its environmental impact becomes increasingly important.

Sustainable Cultivation Practices

Low-Input Crop

Lemongrass is considered an environmentally friendly crop for several reasons:

Drought Tolerance: Once established, lemongrass requires minimal irrigation compared to many other crops, making it suitable for water-stressed regions.

Pest Resistance: The plant's natural compounds repel many pests, reducing or eliminating the need for chemical pesticides in most growing conditions.

Limited Fertilizer Requirements: Lemongrass can thrive in moderately fertile soils without extensive fertilization, especially when grown using sustainable methods like crop rotation.

Perennial Growth: As a perennial grass, lemongrass doesn't require annual replanting, reducing soil disturbance and carbon release.

Soil Conservation Benefits

Lemongrass offers several soil health advantages:

Erosion Control: Its dense, fibrous root system helps prevent soil erosion on slopes and in areas prone to water runoff.

Soil Structure Improvement: The extensive root network enhances soil structure and permeability over time.

Carbon Sequestration: As a perennial grass, lemongrass captures carbon in its biomass and transfers it to the soil, contributing to carbon sequestration. A study published in the Journal of Environmental Management (2017) found that lemongrass plantations in erosion-prone areas reduced soil loss by up to 72% compared to annual crop systems.

Commercial Production Considerations

Sustainable Harvesting

For commercial production, sustainable harvesting practices include:

Selective Cutting: Harvesting only mature stalks while leaving younger growth for future harvests

Proper Timing: Harvesting before flowering to maximize essential oil content and plant vigor

Rotational Harvesting: Implementing staggered

harvesting schedules to maintain continuous plant health

Processing Impacts

The environmental footprint of lemongrass products varies significantly based on processing methods:

Essential Oil Distillation: Traditional steam distillation requires substantial energy and water. Modern energy-efficient distillation methods can reduce this impact by 30-40%.

Dried Herb Production: Solar drying represents the most sustainable approach, while mechanical drying increases the carbon footprint.

Waste Management: Innovative operations compost spent biomass after essential oil extraction or use it for biofuel, creating a closed-loop system.

Lemongrass in Regenerative Agriculture

Forward-thinking farmers increasingly incorporate lemongrass into regenerative agricultural systems:

Intercropping: Planting lemongrass between rows of other crops can reduce pest pressure on companion plants while maximizing land use.

Agroforestry Systems: Lemongrass thrives in partial shade, making it suitable for multilayered agroforestry designs.

Buffer Zones: Planting as windbreaks or riparian buffers helps protect water quality and reduce soil erosion.

A 2019 study in Agroforestry Systems journal documented that coffee plantations interplanted with lemongrass experienced 32% fewer pest

problems while generating additional income from the lemongrass harvest.

Ecological Services

Beyond its direct products, lemongrass provides valuable ecological services:

Pollinator Support: When allowed to flower, lemongrass attracts beneficial insects and pollinators.

Biodiversity Enhancement: Its aromatic properties repel certain pests while attracting beneficial predatory insects that control crop pests.

Phytoremediation Potential: Research suggests lemongrass can help remediate soils contaminated with certain heavy metals, absorbing them into its tissues.

Conservation Concerns

While generally sustainable, certain issues require attention:

Wild Harvesting: In some regions, unsustainable wild harvesting threatens natural lemongrass populations. Certification programs like FairWild address this by promoting sustainable wild collection practices.

Genetic Diversity: As commercial production focuses on high-yielding varieties, preserving diverse lemongrass landraces becomes crucial for long-term resilience.

Invasive Potential: In certain non-native environments, lemongrass can become invasive if not properly managed, though this is uncommon.

Future Sustainability Directions

Emerging approaches to enhance lemongrass

sustainability include:

Renewable Energy Integration: Using solar-powered distillation for essential oil production.

Water Conservation: Implementing drip irrigation and rainwater harvesting.

Carbon Footprint Certification: Developing carbon-neutral or carbon-negative certification for lemongrass products.

Community-Based Production Models: Supporting small-scale growers with fair trade practices.

The environmental profile of lemongrass makes it a promising crop for climate-smart agriculture, particularly in tropical and subtropical regions facing increased climate variability.

Conclusion

Lemongrass is an untapped goldmine for home entrepreneurs looking to create natural, value-added products. From essential oils and skincare to herbal teas and gourmet foods, the possibilities are vast. With minimal investment and growing market demand, venturing into lemongrass-based products can be a rewarding and profitable endeavor.

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Artificial Intelligence for Optimizing Breeding Strategies

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Abstract

Artificial Intelligence (AI) is transforming plant breeding by enhancing breeding strategies through the use of machine learning techniques such as genomic selection, phenotype prediction, and the optimization of breeding programs. AI, through computational models such as machine learning (ML), deep learning and data-driven and training algorithms, can effectively predict gene functions, facilitate high-throughput crop phenotyping, and estimate crop yield and trait performance. As a result, integrating AI with phenomics and genomics tools enables rapid identification of genes linked to specific crop phenotypes, thereby accelerating the progress of crop improvement programs.

Introduction

Artificial intelligence (AI) is a branch of science concerned with creating computers and robots capable of reasoning, learning, and acting in ways that would ordinarily need human intelligence or that use data on a scale that people cannot analyze. AI is used in three critical components of phenomics data management: algorithms and programs for converting sensory data into phenotypic information; development of a model for understanding genotype-phenotype relationships with environmental interactions; and database management for sharing information and resources. Breeding strategies are essential for enhancing traits in plants, animals, and aquaculture, with the aim of improving productivity, disease resistance, and adaptability to environmental changes. Traditional breeding methods, which rely heavily on empirical knowledge, selective breeding,

and trial-and-error, are time-consuming and often limited. However, advances in artificial intelligence (AI) have revolutionized the breeding process, enabling more efficient, data-driven, and predictive approaches. The birth of artificial intelligence (AI) is transforming how breeding strategies are conceived and executed. AI encompasses a range of advanced computational techniques, including machine learning (ML), deep learning and data-driven optimization algorithms that can analyze and interpret vast data sets at an unprecedented scale. These algorithms allow breeders to predict genetic outcomes, optimize crossbreeding strategies, and identify individuals with superior genetic traits much earlier in the breeding process. By leveraging the power of AI, breeders can streamline the selection process, reduce the number of breeding cycles, and significantly accelerate the development of new

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varieties or breeds with improved characteristics. In recent years, the field of plant breeding has witnessed an exemplification shift driven by advancements in artificial intelligence (AI) technologies, including machine learning (ML) and deep learning (DL) technologies. These cutting-edge techniques have transformed our understanding of plant biology. AI-driven plant breeding has been hailed as a game-changing answer in the fight for sustainable agriculture and food security. By creating semi-dwarf, nutrient-responsive, and hybrid cultivars during the last decade, science has already embarked in the green revolution (Bhat *et al.*, 2021). However, in light of the expanding population, shrinking amount of arable land, and changing environment, these factors have necessitated the use of more accurate, high-throughput techniques that can mediate the development of agricultural cultivars more quickly and precisely.

Intend of artificial intelligence (AI)

Artificial intelligence (AI) intends to use technology to mimic some aspects of human intelligence (Yang and Siau, 2018, Raman *et al.*, 2024). With significant economic and social ramifications, this discipline can be defined as a collection of research and methodologies pertaining to computer science and mathematical aspects of statistical modelling, with the aim of creating technological systems that are able to solve problems and carry out tasks or duties that are typically completed by the human mind (Amit, 2018). Artificial intelligence (AI) devices offer a lot of

promise to help farmers by giving them information on things like soil quality, when to plant seeds, where and how to apply herbicides, and when to anticipate pest infestations. Thus, India might experience a farming revolution if AI systems are able to advise farmers on better methods (Roy, 2022). Using AI techniques like high-throughput genomics and phenomics to advanced breeding, it is possible to speed up the process of creating new plant types through marker-assisted selection, genomic selection and prediction (Harfouche *et al.*, 2019). The breeding community is becoming more interested in AI as a result of the technology reaching a mature state and being able to quickly analyse massive volumes of data and find surprising connections. The AI approach from a breeding standpoint, allows individuals to systematize information that is typically already available on the market in a disaggregated form, transforming data into breeding decisions, and thus only considering those tools that are useful to facilitate decision-making processes in crop breeding.

Key AI Approaches in Breeding

Key AI approaches in breeding strategies include a variety of techniques and algorithms that leverage the power of artificial intelligence to enhance breeding efficiency, precision and outcomes. These AI methods are applied in the optimization of plant, animal, and aquaculture breeding programs by analysing vast amounts of data, predicting breeding values, and improving decision-making processes. Below are the most

important AI approaches used in modern breeding strategies:

Machine Learning (ML)

Machine learning algorithms are central to AI-driven breeding programs. They are used to analyse large datasets (such as genomic and phenotypic data) and predict breeding outcomes based on patterns found within the data. Some commonly used ML techniques include: Machine learning algorithms are central to AI-driven breeding programs. They are used to analyse large datasets (such as genomic and phenotypic data) and predict breeding outcomes based on patterns found within the data. Some commonly used ML techniques include:

Support Vector Machines (SVM)

Application: SVM is widely used in breeding for classification tasks, such as identifying individuals with specific genetic markers or traits. In genomic selection, SVM helps categorize genotypes based on predicted performance for desired traits.

Random Forests

Application: Random Forests are ensemble learning algorithms used for trait prediction. They are particularly useful in handling noisy data and identifying important genetic markers that affect traits like yield, disease resistance, or growth.

Deep Learning

Application: Deep learning models (neural networks) can handle complex, nonlinear relationships between data, which is especially important for predicting quantitative traits governed by multiple

genes. In breeding, deep learning can help predict phenotypes from genotypes with high accuracy.

Genomic Selection (GS)

Genomic selection involves using AI models to predict an individual's genetic potential (genomic estimated breeding values or GEBVs) based on dense genetic markers distributed across the genome.

Ridge Regression Best Linear Unbiased Prediction (RR-BLUP)

Application: RR-BLUP is a commonly used model for genomic prediction in breeding programs. It estimates breeding values by analysing relationships between genetic markers and traits, allowing breeders to make more accurate selections.

Bayesian Regression Models

Application: Bayesian methods are used to predict breeding values by incorporating prior knowledge of trait distribution. These models are often employed in genomic selection to estimate the genetic contribution of multiple markers with greater flexibility.

Machine Learning in GS

Application: Machine learning models, such as Random Forests, Gradient Boosting Machines (GBMs), and support vector machines are increasingly being used to enhance the accuracy of genomic selection. These models can handle complex trait architectures and help breeders predict outcomes more effectively.

Marker-Assisted Selection (MAS)

Marker-assisted selection (MAS) uses genetic markers associated with desirable traits to

guide breeding decisions. AI enhances MAS by helping breeders focus on the most relevant genetic markers for trait selection.

Feature Selection Algorithms

Application: AI-driven feature selection methods, such as decision trees and Random Forests, are used to identify the most important genetic markers influencing target traits. These algorithms reduce the complexity of breeding programs and improve the selection process.

Predictive Modelling in MAS

Application: AI models, particularly machine learning techniques, predict the likelihood of specific traits being expressed based on genetic marker data. This allows breeders to make earlier and more informed decisions about which individuals to select for breeding.

Genetic Algorithms (GA)

Genetic algorithms (GAs) are optimization techniques inspired by the natural selection process. They simulate breeding scenarios, evaluate potential solutions, and evolve populations to find the best possible genetic combinations.

Application of Genetic Algorithms

Application: GAs is commonly used to optimize crossbreeding strategies by simulating different mating combinations and selecting the best-performing crosses. They help breeders achieve higher genetic gains and maintain genetic diversity within populations.

Multi-Trait Optimization

Application: GAs is also useful for multi-trait

optimization, where breeders aim to improve multiple traits (such as yield, disease resistance, and drought tolerance) simultaneously. Genetic algorithms simulate possible crosses and evolve them to produce offspring with the best combination of traits.

Hybrid Prediction (Heterosis Prediction)

AI algorithms are used to predict hybrid vigour (heterosis), where the offspring from genetically diverse parents exhibit superior traits compared to both parents.

Deep Learning and Hybrid Prediction

Application: Deep learning models are used to predict heterosis by analysing genetic diversity and patterns from parental genomes. This enables breeders to select the best crosses that maximize hybrid vigour in traits like yield or disease resistance.

Genetic Diversity Analysis

Application: AI models help assess the genetic diversity between breeding populations, guiding breeders in choosing parents with complementary genetic backgrounds that are likely to produce vigorous offspring.

High-Throughput Phenotyping (HTP)

AI plays a crucial role in automating phenotyping tasks, allowing breeders to collect and analyse phenotypic data from large populations more quickly and accurately.

Image Recognition and Computer Vision

Application: AI-powered image recognition and computer vision technologies analyse images from drones or cameras to measure phenotypic traits such as plant height, leaf area, or fruit size. This is a key

component of high-throughput phenotyping, which accelerates the data collection process.

AI Integration of Genomic and Phenotypic Data

Application: AI models integrate phenotypic data with genomic information to improve the accuracy of predictions. This approach allows breeders to better understand the relationship between an individual's genotype and its physical traits.

Optimization Algorithms for Crossbreeding

Crossbreeding aims to combine favourable traits from different populations. AI algorithms optimize crossbreeding strategies to ensure that the best traits are passed on to the offspring while maintaining genetic diversity.

Simulating Breeding Outcomes

Application: Optimization algorithms simulate the outcomes of different breeding scenarios, enabling breeders to predict the performance of offspring before actual crosses are made. These algorithms, such as GAs or deep learning models, refine crossbreeding strategies based on predicted outcomes.

Maximizing Genetic Gain

Application: AI-driven optimization helps breeders maximize genetic gain across multiple traits, ensuring that the next generation carries improved versions of the target traits while maintaining genetic diversity within the population.

Decision Support Systems (DSS) in Breeding

AI-powered decision support systems (DSS) assist breeders in making complex decisions by analysing vast amounts of data and providing action-

able recommendations.

Integration of AI in DSS

Application: AI-driven DSS tools aggregate data from multiple sources (genomic, phenotypic, environmental) and provide breeders with insights into the best individuals to select for breeding, crossbreeding strategies, and trait optimization.

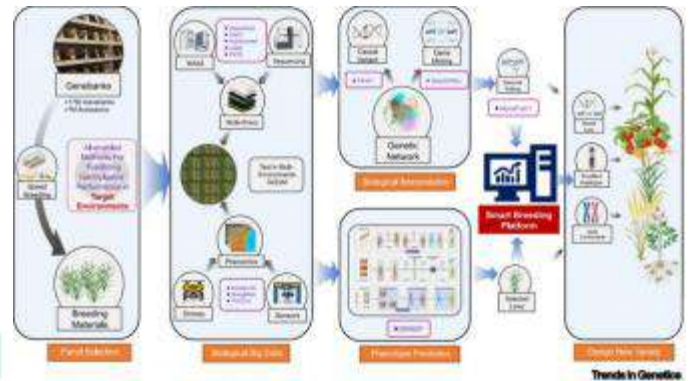


Figure 1. A roadmap of artificial intelligence (AI)-enabled plant breeding. The far left panel depicts the source of germplasm from a genbank that is either used directly or subjected to breeding to utilize omic analyses to generate big data (second panel). The big data from the genbank could uncover genes and predict breeding values (third panel), which would characterize the gene-editing targets and optimal lines for developing next-generation cultivars. Representative AI-based methods are identified in purple boxes. The dotted box represents methods that require development.

Linking of Crop Genome to Phenome with AI

Currently, modern breeding approaches are focused on linking the genotype with the crop phenotype accurately and precisely. In advanced breeding, linking the whole of the genome information to high-throughput phenotypes remains a massive challenge, and is impeding the optimal application of field phenotyping and omics (Harfouche *et al.*, 2019). Germplasm collection and mapping populations can efficiently differentiate the phenomics and genomics data through AI. Crop diversity, single nucleotide polymorphisms (SNPs) detection and selection, quantitative trait loci (QTL) analysis, genome-wide association study (GWAS) analysis, and genomic selection and sequences generate a large amount of data; AI can evaluate and

link the phenomics and genomics data from these big data to improve the breeding approaches. AI related to a computation and training model can predict the gene functional analysis and high-throughput crop phenotyping and also predict the performance of yield and traits of the crop. Therefore, the integration of AI with phenomics and genomics tools can allow for rapid gene identification associated with the crop phenotypes that eventually accelerate crop improvement programs. In Figure, summarize how to apply AI technology to link high-throughput genomics and phenomics, which can result in the production of better breeding strategies.

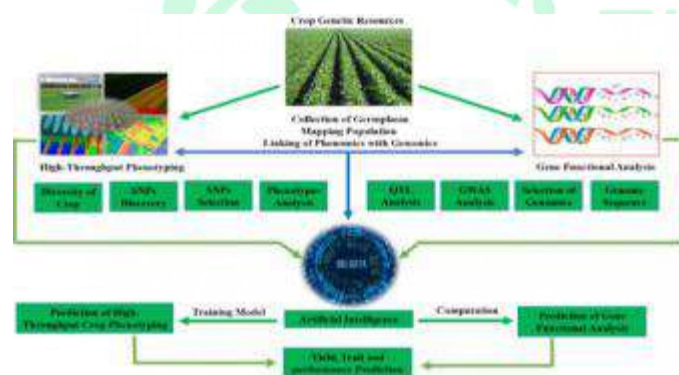


Figure 2. Artificial Intelligence used as a powerful tool for the prediction of high-throughput crop phenotyping and gene functional analysis in modern crop breeding. The high-throughput phenotypic and genotypic data were collected from large crop germplasm and breeding populations. The massive comprehensive database could integrate various resources with AI technology, such as phenotypic diversity of crops, SNPs polymorphisms, QTL analysis, GWAS analysis, genomics selection, and genome sequence. AI technologies are applied to predict the crop phenotype with whole genome prediction, the novel breeding strategies are produced through AI related to computation and training models.

AI Technologies Benefiting Crop Breeding

Artificial intelligence uses computers and

technology to simulate the human mind's problem-solving and decision-making skills (Jarrahi, 2018). AI, often known as machine intelligence, is an area of computer science that focuses on developing and managing technology, which can learn to make decisions and carry out activities independently without the need for human effort (Dwivedi *et al.*, 2021). AI is a broad term that encompasses a wide range of technologies; it is a catch-all word for any software or hardware component that helps with machine learning, computer vision, natural language comprehension, and natural language processing (NLP) (Li *et al.*, 2021). Traditional complementary metal-oxide-semiconductor (CMOS) hardware and the same fundamental computational processes that drive traditional software are used in today's AI (Kok *et al.*, 2019). AI is the most rapidly emerging technology in computer science in today's digital world, and it creates intelligent computers that replicate the intellect of the human mind (Harfouche *et al.*, 2019). For instance, the deep neural network (DNN), artificial neural network (ANN), random forest (RF), and support vector machine (SVM) are a few examples of machine-learning algorithms, as well as advanced hi-tech equipment such as the internet of things (IoT) (Baduge *et al.*, 2022). AI is a fascinating hi-tech system that provides an endless opportunity as far as its agricultural applications are considered; hence, this opens up new frontiers for digital breeding (Montesinos-López *et al.*, 2018). AI technology has been used to accelerate the process of breeding new plant varieties, such as high throughput

genomics and phenomics to advanced breeding. Increasingly, ML methodology has been used in genomic prediction, genomic selection, and marker-assisted selection (Reinoso-Peláez *et al.*, 2022 and Crossa *et al.*, 2017). Many agricultural companies such as Monsanto and John Deere have already invested hundreds of millions of dollars to develop such technologies that can utilize extensive data on soil type, seed variety, and weather to help farmers reduce costs and enhance yields (Faulkner *et al.*, 2014).

Future prospects and conclusion

There has been a notable increase in the discourse surrounding artificial intelligence (AI) in recent times, which has sparked discussions about its potential uses worldwide. Modern plant breeding is required to capitalize on the digital revolution. In order for research and breeding to succeed in the future, they must weigh farmer demands against computer-generated recommendations. Additionally AI will change how businesses grow and compete globally by bringing new manufacturing concepts that will increase profitability. In conclusion, a major advancement in agricultural innovation has been made with the incorporation of AI technology into plant breeding. With its immense potential to improve environmental adaption and speed genetic selection, artificial intelligence (AI) could completely transform crop breeding. AI algorithms may detect desired features, forecast crop performance, and direct breeding decisions with previously unheard-of precision and efficiency by

utilizing enormous volumes of genomic and phenotypic data. In plant breeding, artificial intelligence (AI) technologies are a game-changer. They present hitherto unseen possibilities for tackling urgent agricultural issues and satisfying the needs of an expanding population in a changing climate. Future crop breeding has enormous potential for innovation and worldwide effect as long as breeders stick with and improve AI-driven techniques.

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Mitigating Fertiliser Driven Soil Contamination: Solutions and Strategies

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Abstract

Fertilizers have been instrumental in meeting the nutritional demands of crops and enhancing agricultural productivity. However, indiscriminate and excessive use of fertilizers has emerged as a major source of soil contamination, affecting soil health, water quality, biodiversity and human health. Fertilizers are integral part of current agricultural production as they provide essential mineral elements for positive crop growth and blossoming harvests. Even high yielding varieties of crop plants possibly do not reach to their full potential without getting a balanced dose of fertilizers (Khan *et al.*, 2018). Soil contamination through potentially toxic elements (PTEs) such as heavy metals and nitrates not only deteriorates soil properties but also poses long-term risks to agricultural sustainability. This article expands on the causes, consequences, and mitigation strategies for fertilizer-driven soil contamination, incorporating detailed insights on precision farming, site-specific nutrient management (SSNM), bioremediation, organic fertilizers, controlled-release fertilizers, nano-technological interventions and modern future strategies.

Introduction

Fertilizers, both natural and synthetic, play a critical role in modern agriculture by supplying essential nutrients to crops. They are akin to vitamins for plants without adequate nutrients, plant growth slows, yields drop and food security is threatened. Following the Green Revolution, fertilizer usage skyrocketed globally. India's consumption rose from 1.1 million tonnes in 1950-51 to over 60 million tonnes by 2020. India ranks second in the world and

first among the South Asian Association of Regional Cooperation (SAARC) countries in terms of total fertilizer consumption. Fertilizer accounts for 50 per cent increase in the country's food grain production. Fertilizer consumption in India has increased by 13 times during 1970 to 2020 (Shukla *et al.*, 2022). This growth has ensured food security but also brought environmental challenges. Excessive fertilizer use results in soil contamination through nutrient imbalance, soil acidification, nitrate leaching, loss of

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soil biodiversity and bioaccumulation of heavy metals.

Fertiliser driven soil contamination

Fertilizer-driven soil contamination occurs when the overuse or improper application of fertilizers leads to the accumulation of harmful substances in the soil, negatively impacting its health and functionality. While fertilizers are essential for boosting crop yields and supporting agricultural productivity, their excessive use can disrupt the delicate balance of the soil ecosystem. Soil is the universal sink bearing the utmost burden of the environment pollution. Soil pollution is the serious global concern defined as the contamination of soil with uncharacteristic concentration of the toxic and hazardous substances in the soil that harbors many health hazards (Ramamoorthy *et al.*, 2024). Soils naturally contain heavy metals (HMs) such as cadmium (Cd), mercury (Hg), arsenic (As), chromium (Cr), lead (Pb), etc., but excess application of fertilizers aggravate the situation by lowering the soil pH which facilitates HMs availability (Almasri and Kaluarachchi, 2024). This type of contamination often results from agricultural practices where fertilizers are applied in amounts exceeding the plants' needs, or without considering the soil's capacity to absorb them. Over time, this leads to a buildup of chemical residues and pollutants, including potentially toxic elements (PTEs) like heavy metals and nitrates. These substances can degrade soil structure, reduce its fertility and harm beneficial microorganisms that are crucial for nutri-

ent cycling and overall soil health. The consequences of fertilizer-driven soil contamination extend beyond the soil itself. It can also lead to water pollution through runoff and leaching, affecting both surface and groundwater quality. This can have detrimental effects on aquatic ecosystems and pose risks to human health through contaminated drinking water and food sources. Additionally, contaminated soil can impair plant growth, reduce crop quality and introduce harmful substances into the food chain, further exacerbating the environmental and health impacts.

Causes of fertiliser driven soil contamination

Over-application of Fertilizers: Farmers often apply fertilizers beyond recommended doses, leading to nutrient runoff and leaching.

Heavy Metal Accumulation: Fertilizers such as phosphates contain trace amounts of cadmium, lead, and arsenic.

Soil Acidification: Ammonium-based fertilizers lower soil pH, causing solubilization of toxic metals.

Groundwater Pollution: Excess nitrogen leaches into aquifers, leading to nitrate pollution and human health hazards like methemoglobinemia.

Loss of Soil Microbial Diversity: High fertilizer inputs disrupt microbial balance, affecting soil resilience and nutrient cycling.

Eutrophication: Fertilizer runoff into water bodies promotes algal blooms, depleting oxygen and harming aquatic life.

Impact on environment and human health

Soil pollution is the decrease in the product-

ivity of soil due to the presence of soil pollutants. Moreover, soil pollutants have an adverse effect on the physical, chemical, and biological properties of the soil and reduce its productivity. Understanding and developing innovative techniques play a crucial role in effectively combating environmental pollution (Ranieri *et al.*, 2016). Contamination extends beyond soil health. Excess fertilizer use can result in leaching and runoff, affecting water bodies and ecosystems. Eutrophication from phosphorus runoff leads to algal blooms, disrupting aquatic life. Accumulated nitrates and heavy metals in crops lead to nitrate poisoning, liver and kidney disorders, increased cancer risks, immune system suppression and endocrine disruption among humans.

Solutions and strategies

Precision Agriculture: Precision agriculture uses technologies such as GPS, yield monitors, variable rate technology and remote sensing to optimize fertilizer use. It ensures nutrients are applied precisely where and when they are needed, reducing wastage and environmental impact.

Site-Specific Nutrient Management (SSNM): SSNM involves managing nutrient applications according to specific field conditions and crop needs. It improves nutrient use efficiency, enhances yield, and reduces environmental harm. Tools like leaf color charts, SPAD meters and Green Seeker devices assist farmers in real-time monitoring.

Use of Organic and Bio-fertilizers: Organic fertilizers like compost, green manure, and bio-fertilizers enhance soil organic matter, boost

microbial activity, and prevent soil acidification. They promote sustainable agriculture by improving soil structure and long-term fertility.

Controlled Release and Nano Fertilizers: Controlled release fertilizers and nano-fertilizers release nutrients gradually and in sync with plant demands. They minimize nutrient loss through leaching or volatilization, improve fertilizer use efficiency, and reduce contamination risks.

Bioremediation Techniques: Bioremediation employs microorganisms and plants to degrade or immobilize contaminants in soils. Phytoremediation, thermal remediation and microbial-assisted processes are sustainable ways to reclaim contaminated soils.

Conclusion

While fertilizers remain indispensable for global food production, their reckless use is a ticking environmental time bomb. Integrated soil fertility management, combining technological innovations with sustainable agricultural practices, is essential for mitigating soil contamination. A shift towards balanced nutrient management and environmentally responsible farming practices will pave the way for resilient soils, safer food, and a healthier planet.

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Biocontrol Agents and their Role in Sustainable Agriculture

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Abstract

Sustainable agriculture targets to fulfil the food demands of a growing population while reducing environmental degradation. In this scenario, biocontrol agents (BCAs) living organisms such as beneficial bacteria, fungi, insects, nematodes, and their metabolic products provide promising alternatives to chemical pesticides. These biological strategies are gaining popularity due to their higher specificity, ecofriendly nature and ability to improve soil and plant health. This article provides a thorough overview of the various mechanisms, applications, and recent advances in biocontrol technologies. We also discuss the challenges and future strategies for incorporating BCAs into conventional agricultural practices.

Introduction

Sustainable agriculture is essential for the worldwide availability of food, particularly in the context of changing climates and degradation of the environment. Chemical inputs are effective but resulted in biodiversity loss, pesticide resistance and contamination including soil and water (Pretty and Bharucha, 2015). Biocontrol agents offer a natural alternative by suppressing pests and pathogens with living organisms or their products, which adheres to ecological balance and long-term productivity principles (Chandler *et al.*, 2011).

Biocontrol agents can give good results when applied as single culture or consortia, and their effectiveness is enhanced when combined with environmentally tailored formulations (Lacey *et al.*, 2015).

Mechanism of action

Antibiosis: Inhibit pathogen growth by production

of antimicrobial compounds (e.g., lipopeptides by *Bacillus* spp.)

Competition: Mainly for space and nutrients, particularly in the rhizospheric zone.

Mycoparasitism and Predation: Fungal Biocontrol agents such as *Trichoderma* spp. parasitize phytopathogens by secreting cell-wall degrading enzymes.

Induced Systemic Resistance (ISR): Many rhizospheric bacteria and fungi trigger plant defense responses to control disease (Pieterse *et al.*, 2014).

Molecular Insights into Biocontrol Mechanisms:

Recent molecular biology advances have helped us better understand the signalling pathways, gene expression, and interkingdom communication that take place during plant-microbe-insect interactions.

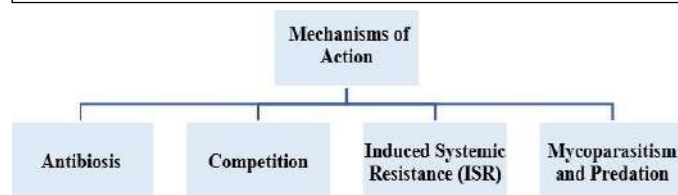
Gene Expression in BCAs: *Bacillus subtilis* expresses genes such as *srfA*, *fenA*, and *ituD*, which encode important antimicrobial lipopeptides like

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Table 1: Classification of Biocontrol Agents

Category	Examples	Target
Microbial Agents	<i>Bacillus</i> , <i>Pseudomonas</i> , <i>Trichoderma</i> , <i>Streptomyces</i>	Fungal/bacterial pathogens, nematodes
Entomopathogenic Nematodes	<i>Steinernema</i> , <i>Heterorhabditis</i>	Insect larvae
Entomopathogenic Fungi	<i>Beauveria bassiana</i> , <i>Metarhizium anisopliae</i>	Whiteflies, aphids, beetles
Predatory Insects	<i>Coccinellidae</i> , <i>Chrysopidae</i>	Aphids, mites
Parasitoids	<i>Trichogramma</i> spp., <i>Encarsia formosa</i>	Lepidopteran and whitefly eggs
Viral Biopesticides	Baculoviruses	Caterpillars and lepidopteran pests



surfactin, fengycin, and iturin (Ongena and Jacques, 2008). Similarly, *Trichoderma harzianum* expresses *ech42*, *tvsp1*, and *nag1*, which all encode enzymes that degrade chitin and glucan.

Plant Responses to BCAs: Defense related genes such as PR1, LOX, and PDF are upregulated after the treatment of plant with plant growth-promoting rhizobacteria, indicative of defense mechanism including both systemic acquired resistance (SAR) and induced systemic resistance (ISR) (Pieterse *et al.*, 2014). ISR involves jasmonic acid and ethylene signaling, whereas SAR is salicylic acid-dependent.

Applications in Sustainable Agriculture

Pest and Disease Management: BCAs are an important part of Integrated Pest Management (IPM), which reduces reliance on chemical pesticides. *Beauveria bassiana* is effective against whiteflies and aphids, while *Pseudomonas fluorescens* is commonly used to control soil-borne pathogens such as *Fusarium* and *Rhizoctonia* spp. (Glick, 2012).

Abiotic Stress Tolerance: Some BCAs enhance tolerance to drought, salinity, and heat stress by influencing phytohormones (e.g., auxins, cytokinins)

and stress-responsive genes (Ngumbi and Kloepper, 2016).

Enhancing Soil Health: BCAs improve soil structure and biodiversity, which helps to maintain long-term fertility of the soil. *Trichoderma* spp. increases root biomass and enzymatic activity in soil (Yadav *et al.*, 2020).

Reduction of Chemical Inputs: BCAs lower input costs and agricultural environmental impact by limiting pesticide and fertiliser use.

Supporting Organic Farming: Biocontrol is critical in certified organic systems that do not allow synthetic chemicals.

Climate-Resilience: Microbial BCAs enhance crop resistance to drought, salinity, and temperature by influencing stress-responsive genes and antioxidant systems (Ngumbi and Kloepper, 2016).

Commercial Biocontrol Products and Market Trends

More than 500 commercial biocontrol products are available globally. Some examples are shown in the Table 2.

The biopesticide market is expected to grow from USD 5.5 billion in 2020 to USD 13.9 billion by 2027, with significant demand from North America, Europe, and Asia-Pacific.

Integration with Other Sustainable Practices

Table 2: Commercial Biocontrol Products and Market Trends

Product Name	Active BCA	Target Pest/Disease	Company
Serenade®	<i>Bacillus subtilis</i> QST 713	Fungal diseases	Bayer CropScience
Bio-Magic®	<i>Beauveria bassiana</i>	Whiteflies, thrips	Valent BioSciences
Ecofit™	<i>Trichoderma viride</i>	Soil pathogens	T. Stanes & Company
Biobit® HP	<i>Bacillus thuringiensis</i> kurstaki	Lepidopteran larvae	Certis USA
NemaShield®	<i>Steinernema feltiae</i>	Fungus gnats	Biobest

Biocontrol agents are more effective when integrated with:

- ✓ Organic amendments (compost, vermicompost) for microbial support.
- ✓ Biofertilizers such as *Azospirillum* or *Rhizobium* for synergistic effects.
- ✓ Crop rotation and intercropping to disrupt pest cycles.
- ✓ Digital agriculture for precision timing of BCA applications.

Challenges in Implementation

Inconsistency in Field Performance: In lab conditions microbes can grow easily but the environmental factors in field affects microbial survival and activity.

Limited Shelf Life: Many BCAs are sensitive to various factors such as UV, temperature, and desiccation.

Regulatory Barriers: Commercialisation is limited by stringent registration procedures, especially in developing countries.

Farmer Awareness and Adoption: Knowledge gaps and limited access hinder widespread use.

Advances and Future Perspectives

Genomics and Omics Approaches: Genomic and metagenomics advances are helping to decode microbial communities and identify new strains that will be used as biocontrol (Timmusk *et al.*, 2017).

Formulation Innovations: Bioencapsulation, Nano-formulations, and microbial consortia are increasing BCA stability and efficacy.

Policy and Extension: Government support for biopesticide development, farmer training, and incentives are essential for accelerating adoption.

Conclusion

Biocontrol agents are essential for promoting a sustainable agricultural system. BCAs, with their numerous functions in pest control, plant growth promotion, and stress reduction, are a viable alternative to chemical inputs. Strategically incorporating BCAs into farming practices can help to restore ecological balance, increase food security, and lower the environmental impact of modern agriculture.

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Role of Soil Fertility in Plant Disease Management

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Abstract

Soil fertility plays a critical role in plant health by influencing the microbial ecosystem, nutrient availability, and disease resistance (Trivedi *et al.*, 2020). Key factors such as organic matter content, macronutrient balance (nitrogen, phosphorus, potassium), and soil microbiota diversity contribute to disease suppression. Biologically active soils with optimal fertility can reduce pathogen prevalence by promoting antagonistic microorganisms that outcompete or inhibit harmful pathogens. Furthermore, specific amendments such as compost, biochar, and organic fertilizers have been shown to enhance soil health, leading to improved plant resistance against fungal, bacterial, and viral infections. Understanding the mechanisms by which soil fertility mitigates plant diseases offers sustainable strategies for agricultural disease management, reducing the reliance on chemical pesticides. Recent findings on the role of soil fertility in plant pathogen suppression and suggests future research directions for optimizing soil management practices to enhance plant health and productivity.

Introduction

Soil fertility refers to the ability of soil to provide essential nutrients to plants for their growth and development. It is a critical aspect of agriculture and gardening, as fertile soil supports healthy crop yields. Factors influencing soil fertility include the presence of organic matter, soil texture, pH levels, and the availability of macro and micronutrients such as nitrogen, phosphorus, and potassium. Improving soil fertility can involve practices such as adding organic amendments like compost or manure, using cover crops, and implementing crop rotation. Healthy soil with good organic content enhances its structure, improving aeration, drainage, and water retention, reducing soil erosion and drought stress.

Soil testing is also important to determine nutrient levels and pH, allowing for targeted amendments. Sustainable practices aim to maintain or enhance soil fertility while minimizing environmental impact. Overall, understanding and managing soil fertility is essential for sustainable agriculture and food security.

Soil-borne pathogens and their effects

Soil-borne pathogens are microorganisms that live in the soil and infect plants, causing significant diseases that lead to economic losses in agriculture and horticulture (Table 1). These pathogens include fungi, bacteria, nematodes, and viruses that persist in the soil for extended periods, often spreading through water, soil particles, and

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Table 1: Types of soil-borne pathogens and their effects

Pathogen Type	Examples	Effects on Plants
Fungi	<i>Fusarium spp.</i> , <i>Phytophthora spp.</i> , <i>Rhizoctonia solani</i> , <i>Verticillium dahliae</i>	Root rot, wilt, damping-off, vascular blockage, yellowing, and plant death
Bacteria	<i>Ralstonia solanacearum</i> , <i>Agrobacterium tumefaciens</i> , <i>Clavibacter michiganensis</i>	Wilting, tumour, cankers, necrosis, reduced growth
Nematodes	<i>Meloidogyne spp.</i> , <i>Heterodera spp.</i> , <i>Pratylenchus spp.</i>	Root gall formation, stunted growth, nutrient deficiency symptoms
Viruses	<i>Tobacco mosaic virus (TMV)</i> , <i>Tomato spotted wilt virus (TSWV)</i>	Mosaic patterns on leaves, curling, yellowing, reduced vigour

infected plant material. Their impact ranges from stunted growth and root rot to complete plant death, affecting food security and crop yields worldwide.

Effects of soil-borne pathogens

Reduced Crop Yields: Many pathogens cause root damage, restricting nutrient and water uptake, leading to poor plant growth and low yields.

Economic Losses: Infected fields often require expensive management strategies, including soil treatments, crop rotation, and resistant varieties.

Soil Health Deterioration: Persistent pathogens alter microbial communities, making soils less productive over time.

Disease Spread: Many soil-borne pathogens can spread through contaminated tools, water, and infected seeds, increasing their impact.

Increased Vulnerability to Environmental Stress: Infected plants become more susceptible to drought, nutrient deficiencies, and secondary infections.

Management strategies of plant disease

Crop Rotation: Rotating non-host crops can break the pathogen cycle.

Soil Solarization: Using plastic covers to trap heat and kill pathogens in the soil.

Biological Control: Introducing beneficial microbes like *Trichoderma spp.* to suppress pathogens.

Resistant Varieties: Growing genetically resistant crop varieties.

Sanitation Practices: Cleaning tools, using pathogen-free seeds, and removing infected plant material.

Chemical Control: Fungicides, bactericides, and nematicides can be used, but with caution to avoid resistance buildup.

Role of soil fertility in disease suppression

Soil fertility is essential for maintaining healthy ecosystems and agricultural productivity. It refers to the ability of soil to provide essential nutrients to plants, which is influenced by factors such as organic matter content, pH, and microbial activity. A diverse community of soil microorganisms, including bacteria, fungi, and protozoa, thrives in fertile soils. These beneficial microbes can produce antibiotics, outcompete harmful pathogens for resources, and enhance nutrient availability, all of which contribute to disease suppression. Moreover, nutrient-rich soils support vigorous plant growth, which is critical for developing natural defense mechanisms against diseases. Plants can produce secondary metabolites and other compounds that deter pathogens when they are healthy and well-nourished. The presence of organic matter, such as

decomposed plant material, not only enriches the soil with nutrients but also improves its structure, leading to better aeration and water retention. This improved environment helps plants withstand stress and reduces the likelihood of disease outbreaks. Maintaining soil fertility is vital for promoting plant health and resilience, ultimately leading to lower disease incidence and improved agricultural outcomes. Sustainable practices, such as crop rotation, cover cropping, and organic amendments, can enhance soil fertility and support the beneficial microbial communities necessary for disease suppression.



Figure 1: Role of soil fertility

Organic matter and its role in disease management in soil

Organic matter plays a crucial role in soil health and disease management by enhancing microbial diversity, improving soil structure, and increasing the availability of essential nutrients. It fosters beneficial microbial communities that suppress soil-borne pathogens, making it a key component of sustainable agricultural practices. Organic amendments such as compost, manure, and

biochar contribute to natural disease suppression through competition, predation and induced resistance in plants. Key mechanisms through which organic matter aids in disease management include:

Microbial Competition & Antagonism: Beneficial microbes outcompete pathogens for resources, limiting their growth.

Induced Systemic Resistance (ISR): Certain organic compounds trigger plants' immune responses, making them more resistant to infections.

Improved Soil Structure: Enhanced aeration and water retention reduce pathogen proliferation in compacted, anaerobic soils.

Nutrient Cycling: Organic matter boosts microbial activity that converts nutrients into plant-available forms, promoting healthier crops.

Production of Suppressive Compounds: Decomposition of organic materials generates compounds that inhibit pathogen activity.

Soil amendments for disease control

- ✓ Soil amendments can significantly increase the diversity of soil microorganisms, which is crucial for maintaining a balanced ecosystem. A diverse microbial community can enhance nutrient cycling and improve plant health.
- ✓ Certain soil amendments, like biochar (Celestina *et al.*, 2019), not only improve soil structure and nutrient retention but also sequester carbon, helping to mitigate climate change by reducing greenhouse gas emissions.
- ✓ The practice of using soil amendments for disease control dates back to ancient civilizations,

where farmers used organic materials like animal waste and plant residues to enhance soil fertility and combat pests.

- ✓ Some soil amendments, such as mycorrhizal fungi, form symbiotic relationships with plant roots, improving nutrient uptake and enhancing plant resilience against diseases.
- ✓ The effectiveness of soil amendments can vary based on soil type, climate, and the specific crops being grown, making it essential for farmers to tailor their amendment strategies to their unique conditions.
- ✓ Incorporating green manures, which are cover crops grown specifically to be tilled back into the soil, can improve soil health and suppress weeds, further reducing the need for chemical herbicides (Wang *et al.*, 2017).
- ✓ The use of certain soil amendments can lead to the production of allelochemicals, which are natural compounds that can inhibit the growth of pathogens and pests in the soil.
- ✓ Soil amendments can also enhance the soil's ability to retain moisture (Urrea *et al.*, 2019; Ding *et al.*, 2020), which is particularly beneficial in arid regions where water scarcity is a significant concern for agriculture.
- ✓ The application of organic amendments can lead to a phenomenon known as “soil aggregation,” where soil particles clump together, improving aeration and water infiltration.

Conclusion

Soil fertility plays a pivotal role in enhancing

plant health and reducing the severity of plant pathogens. A well-balanced, nutrient-rich soil strengthens plant immunity, allowing crops to resist infections more effectively. Key nutrients such as nitrogen (N), phosphorus (P), and potassium (K), along with essential micronutrients, contribute to robust plant growth and the activation of natural defense mechanisms against pathogens. Beyond nutrient availability, soil fertility also influences microbial diversity, which is essential for disease suppression. Beneficial microbes outcompete harmful pathogens, reducing their impact and preventing outbreaks. Additionally, organic matter enrichment, through compost and biofertilizers, improves soil structure, aeration, and water retention, creating an environment unfavourable for disease-causing organisms.

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Napier Grass: A Solution to Round-the-Year Requirement of Dairy Industry

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Abstract

The dairy industry in India is growing expeditiously, providing regular and quick income to farmers and rural areas with small landholdings at a time when the weather changes have led to lesser production from agricultural land. The efficiency of the dairy industry lies in high milk yield and proper sale of other dairy and animal products. To maintain the dairy animals, a nutrient-rich and economic source of both feed and fodder is required. Napier grass has emerged as a solution to year-round fodder production efficiently and economically. Napier grass and its hybrid varieties have proved to be a nutrient-rich, fast-growing and low-maintenance requiring fodder crop.

Introduction

Napier grass (*Pennisetum purpureum* Schumacher) is a tropical grass and is an essential part of the diet of many elephants and is commonly known as elephant grass. It is native to Sub-Saharan tropical Africa, growing well in tropical and sub-tropical conditions as a result, the grass was introduced to many tropical and sub-tropical countries. Napier grass has naturalized in Africa, Asia and Latin America, comprising more than 50% of its total population. Further, it is cultivated all over the world as a preferred fodder crop because of its high yield and low maintenance. Currently, agriculture is facing severe challenges from the vagaries of nature, i.e., climate change, droughts, floods, etc. As a result, the agricultural productivity is unable to make a steep rise despite the introduction of various hybrids. Being an agrarian economy, Indian farmers need to have a supplementary source of income, which can

be well met by dairy farming. The major requirements of the dairy industry are high-yielding dairy animals and economical feed and fodder for those animals.

Napier Grass as a Fodder Crop

In India, there is only a limited area available for fodder cultivation (8.6 million ha), which has to be used efficiently to meet the requirements of the growing livestock population. Fodder is a cheap source to provide nutrients and comprises 2/3 of the ration feed to livestock. Fodder and forage crops like maize, sorghum, berseem, barley, oats and cowpea are nutritious and palatable but are seasonal, causing scarcity in seasons when they are not cultivated. The fodder crops are mostly cereals and require tillage, land preparation and irrigation in each crop season, making them costly to cultivate. Grass crops have been found better for fodder as they propagate by vegetative means and require less maintenance and

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can be grown year-round. Napier grass is a perennial crop having vegetative propagation with high nutritive values, making it a desired fodder crop. Hybrid Napier, also known as Bajra-Napier hybrid, Napier Bajra Hybrid, King grass and Elephant millet, are widely distributed in tropical and sub-tropical regions of Africa, Asia and Southern Europe. This hybrid has been derived from the cross between *Pennisetum glaucum* and *Pennisetum purpureum*. It is a tall-growing, altitudinal and deep-rooted grass crop.

Desired Characters of Napier Grass as Fodder

- ✓ It has multiple tillering and very good tonnage throughout the year, providing better yield per unit crop.
- ✓ It grows well in saline soil, wastelands, bunds and terraces, growing well in arid and semi-arid agro-climatic zones of India.
- ✓ Napier grass has high yield potential, palatability, resistant to various climatic and soil conditions, having high nutritive value.
- ✓ Once established, the crop supplies green fodder for five years with aromatic silage production and good quality due to fermentation accompanied by the production of lactic acid, acetic acid and butyric acid.
- ✓ Silage produced from Napier grass can be used in off off-season when Napier is not cultivated. Hence, it can be used both in regions where they are cultivated and even where they are not cultivated in the form of silage.

Production of Quality Napier Grass

Selection of Variety: Use of high-yielding varieties is necessary for higher production per unit area. The variety selected should be suitable to the climatic conditions of that region, should be resistant to salinity and drought, and should have a greater number of tillers with reduced maturity duration. A few varieties with their characters are as follows:

Variety	Characters
CO-3	High yield potential, High protein content (~8-11%)
CO-4	More tillering and soft stems, Better digestibility and palatability, Suitable for multi-cut harvesting
NB-21	Good drought resistance, High green fodder yield with juicy stems, Suitable for rain-fed areas
IGFRI Hybrid NAPIER-3 (HN-3)	High biomass yield, High crude protein (~11%), Tolerant to moderate drought conditions
PBN 233	Vigorous growth with profuse tillering, Resistant to disease and pests

Planting of Hybrid Napier: It is propagated by root and stem cuttings. For higher yield, the spacing of 60x90 cm, 90x90 cm and 90x120 cm is adopted based on space and soil status. The CO-3 variety of hybrid Napier has shown the highest green fodder yield when planted on furrows and buried in soil.

Fertilizer and Nutrient Requirement

Napier, being a C₄ grass, has high fertilizer dose requirements for greater yield. Application of NPK in the recommended dose of 150:50:40 Kg ha⁻¹ where the phosphorus (P) and potassium (K) dose are applied basally before planting and nitrogen (N) is applied in two doses, first 50% of N is applied basally before sowing and rest 50% is applied at on 30 DAS. For better yield, 20 t ha⁻¹ of farm yard manure is added to the soil. This composition has led to an increase in the total dry matter production of

the crop.

Maturity and Harvesting Management: Maturity of the grass is determined by its height. As the plant grows and reaches a height of 1-3 m, it is time to harvest. Worldwide, Napier grass is harvested multiple times with an average of 6 harvests in a year, it can be harvested to maximum of 11 times a year to increase. All research works have concluded that yield increases with an increase in harvesting index.

Nutritional Quality of Napier Grass: It was found that there was a significantly higher quantity of crude protein, crude fibre, total ash and mineral content as compared to other fodder crops. A recorded higher quantity of dry matter (17%), ether extract (4.34%) and ash (16.06%) than sorghum; higher crude protein (10.92%) compared to maize. This makes the Napier hybrid both quantitatively and qualitatively superior to other perennial grasses.

Potential to Salinity and Temperate Zone

Salinity: Salinity is one of the prime threats to the agricultural system, where the irrigated lands are prone to developing salinity, causing a reduction in yield and survival of plants. Napier grass, being a C₄ plant, has higher water use efficiency, which helps it survive under saline conditions.

Temperate Region: Napier grass is a tropical crop hence, it is difficult for it to survive in temperate conditions, still it can be cultivated in temperate regions with better management practices. Napier survives well in 25°C- 40°C and the growth slows down below 15 °C and ceases at 10°C, being a winter

dormant crop, it is also sensitive to frost.

Chemical Composition of Napier Grass

Items	Components (g kg ⁻¹ DM)
Dry Matter (g kg ⁻¹ fresh weight)	240
OM	914
CP	104
NDF	555
Ca	2.6
Mg	2.6
Na	0.3
K	53.9
Ash	86
Soluble oxalate	23
ME (MJ Kg ⁻¹)	7.5

OM, Organic matter; CP, Crude protein; NDF, Neutral detergent fibre; Ca, Calcium; Mg, Magnesium; Na, Sodium; K, Potassium; ME, Metabolizable energy

Future Prospects and Conclusion

Napier grass has been widely grown by the small farmers of the country, but many farmers are unable to exploit its true potential. The cultivation of Napier grass with the use of hybrid varieties and proper management i.e., (i) increasing plant density and (ii) increasing harvesting frequency, can superficially increase the yield both qualitatively and quantitatively. Production of silage from harvested grass and its storage and transport can help fulfil the country's fodder requirement. Extensively cultivating Napier grass can meet the growing demand for fodder with the growing livestock population. The aim to improve the quality of dairy products can only be achieved by improving the quality of feed in livestock, which can be assured by Napier grass as fodder. The growing demand for dairy products has increased the demand for fodder, and it is a big challenge to provide the required fodder with limited space for cultivation or to procure it economically. Cultivation of perennial grass has emerged as a

solution and Napier grass is a leading fodder crop that can help bring sustainability to agriculture. In conclusion, Napier grass is essential to optimise yield and quality to optimise marginal and small farmers economically, which can also play a crucial role in bringing food security to the vast world.

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Value Addition in Mulberry: An Innovative Approach for Entrepreneurship Opportunities in Rural Areas

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Abstract

Mulberry (*Morus alba*) fruit and plant possess immense potential for value addition, offering innovative avenues for entrepreneurship, especially in rural areas. Traditionally associated with sericulture, mulberry's nutritional and medicinal properties have broadened its scope for diversified utilization. The fruit is rich in bioactive compounds such as anthocyanins, flavonoids, vitamins, and minerals, which contribute to its use in health-focused products like herbal tea, functional beverages, natural colorants, jams, and syrups. Additionally, other parts of the plant, including leaves, bark and roots are utilized in traditional medicine and animal feed. By adopting small-scale, cost-effective processing techniques, rural communities can transform raw mulberry resources into marketable products, thus enhancing income, creating jobs and promoting sustainable development. This approach not only supports local economies but also encourages the use of indigenous resources for innovation in agri-business.

Introduction

Mulberry cultivation is the cornerstone of sericulture, particularly in the production of mulberry silk, which is renowned for its superior quality and global market demand. While traditionally grown to feed silkworms, mulberry (genus *Morus*) offers a wide range of possibilities beyond its conventional use, presenting significant potential for value addition. These include the utilization of mulberry leaves, fruits, bark and roots in diverse industries such as food processing, pharmaceuticals, nutraceuticals, cosmetics and even textiles. In rural areas, especially those engaged in sericulture, value addition in mulberry can play a transformative role in promoting entrepreneurship, enhancing livelihood

and driving local economic development (Ravikumar *et al.*, 2012). Mulberry leaves are rich in protein, vitamins, and bioactive compounds and are now being explored for their health benefits, including anti-diabetic, antioxidant and anti-inflammatory properties (Andallu and Varadacharyulu, 2007). Mulberry fruits are also gaining popularity for their nutritional and medicinal value, finding a place in juices, jams, wines and dietary supplements. Additionally, mulberry-based products such as leaf powder, tea, animal feed and herbal formulations are entering commercial markets, creating new opportunities for small and medium rural enterprises (Chattopadhyay *et al.*, 2013). With the growing consumer demand for natural and plant-based produ-

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Table 1: Value Addition and Potential Uses of Mulberry Leaf

Value addition of Mulberry leaf	Uses	References
Mulberry Leaf Tea	Caffeine-free; acts as a laxative, relieves respiratory inflammation, supports liver/lung health, and reduces blood sugar and cholesterol.	Tulasi and Viswanath (2013)
Mulberry Leaf Juice and Culinary Uses	Promotes healthy skin; relieves throat irritation; used in foods like pakoda and dhokla; valued for natural sweetness and potential in food industry.	Iyengar <i>et al.</i> (2007)
Medicinal Applications	Used in pharmaceuticals; provides antioxidant, anti-diabetic, anti-cancer, anti-obesity benefits; treats skin, GI, and neurological issues.	Sujathamma <i>et al.</i> (2013) and Sharma <i>et al.</i> (2020)
Animal Feed	Nutrient-rich feed for livestock; superior to grasses and legumes; rich in carotene and vitamin A; enhances poultry health and egg production.	Sudo <i>et al.</i> (2000)
Phytoremediation	Supports soil remediation; roots absorb nutrients and heavy metals (Pb, Cd, Cu); promotes ecological sustainability in moriculture	Zhou <i>et al.</i> (2015) and Ghosh <i>et al.</i> (2017)

Table 2: Value addition of Mulberry Fruit

Mulberry Component	Uses	References
Mulberry Fruit	Mulberry fruit aids digestion, lowers cholesterol, regulates blood sugar and may help prevent cancer. It also boosts circulation, supports vision and promotes brain health.	Singhal <i>et al.</i> (2010)
Mulberry Fruit Powder	Rich in anthocyanins; 100 mg powder from 10 g dried fruit; has anti-aging properties; supports heart health, cancer prevention, and aids carbohydrate digestion	Singhal <i>et al.</i> (2009)
Jam, Jellies, Syrup, Squash	High sugar content ideal for sweet products; used in medicine for flavor and color; helps manage hyperlipidemia, constipation, insomnia, and supports immunity.	Buhroo <i>et al.</i> (2018)
Natural Food Colorant	Rich in anthocyanins (cyanidin-3-glucoside and cyanidin-3-rutinoside); provides vibrant natural color; alternative to synthetic dyes with added health benefits	Zhang <i>et al.</i> (2018)
Mulberry Fruit Tea	Traditional Chinese remedy; made from 'Sangshengao' mulberry paste; used to treat hearing and vision deficiencies.	Buhroo <i>et al.</i> (2018)
Mulberry Fruit wine	Rich in Vitamin C; made from overripe or sour fruit; popular in Europe, especially among women; believed to support heart and digestive health.	Alakbarov <i>et al.</i> (2000)
Mulberry Branches, Wood, and Twigs	Used in cosmetics (hair lotions, moisturizers), furniture, fuel, sports goods (due to wood flexibility), baskets, and “artificial cotton” for textiles.	Wani <i>et al.</i> (2020)
Mulberry Bark and Roots	Bark used for paper pulp and rope making; root bark used in traditional medicine (cough, asthma); ethanolic extract has anti-HIV potential (flavonoids like Moricin, Mulberrofurin D, G, K).	Buhroo <i>et al.</i> (2018); Wani <i>et al.</i> (2020)

cts, the scope for developing a mulberry-based value chain is expanding. This not only improves the profitability of existing sericulture activities but also enables diversification, reduces dependency on raw silk sales and promotes sustainable rural entrepreneurship. By integrating modern processing technologies, skill training and market linkages, value addition in mulberry can become a viable model for inclusive development in rural economies (Devi and Das, 2016). This article aims to explore the various value-added applications of mulberry and assess their potential to foster entrepreneurship and self-reliance in rural communities.

Value addition of Mulberry Fruit

Mulberry is a flavorsome, delicate, and healthy dessert fruit, often referred to as a “third-generation fruit” due to its nutritional and therapeutic value. It is toxin-free and rich in phytochemicals such as anthocyanins, benzoic acids, flavonoids, flavonols, and hydroxycinnamic acids, all of which exhibit strong antioxidant properties (Yang *et al.*, 2016).

Conclusion

Value addition in mulberry offers a transformative opportunity to stimulate rural entrepreneurship and sustainable development. By moving beyond traditional sericulture and exploring diverse applications such as mulberry-based food products, herbal supplements, cosmetics, and eco-friendly

textiles, rural communities can tap into high-value markets and increase income sources. This innovative approach not only enhances the economic viability of mulberry cultivation but also promotes skill development, local employment, and self-reliance. With the right support in terms of training, infrastructure, and market linkage, value-added mulberry products can become a cornerstone of rural entrepreneurship, fostering inclusive growth and reducing migration to urban areas.

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Consequences of Startup Failure in India: A Review

Gauri Agarwal and Suhaib Khan

Abstract

Startups serve as crucial catalysts for innovation and economic advancement, yet a significant portion of them encounter failure, especially in developing economies like India. Even with the rise in entrepreneurial initiatives in the nation, the failure rate for startups continues to be remarkably high, with nearly 90% of new enterprises ceasing operations within their initial five years. This paper investigates the main factors contributing to such elevated failure rates in India, identifying critical challenges such as market misalignment, financial mismanagement, regulatory hurdles, and leadership weaknesses. Moreover, the study emphasizes how India's distinctive socio-economic and regulatory landscape, characterized by underdeveloped infrastructure and intricate taxation systems, intensifies the likelihood of failure. The paper further explores possible strategies to reduce these failures. By examining these matters, the paper presents actionable suggestions to assist in strengthening the resilience of the startup ecosystem in India.

Introduction

Startups are nascent enterprises that are generally established with the intention of addressing a particular issue or providing a novel solution in an innovative or distinctive manner. These firms are recognized for their capacity to grow quickly, often depending on technology or unique business models to disrupt current markets. They are usually marked by high levels of unpredictability and risk, while simultaneously presenting considerable prospects for growth and returns if they succeed. India has emerged as one of the most promising and rapidly evolving startup ecosystems worldwide.

Factors Contributing to Startup Failure in India

Lack of Market Demand: A primary cause of startup failure is the failure to address a considerable market demand. Unsuccessful startups frequently

miscalculate the demand for their products or services, which leads to their incapacity to grow and maintain the business.

Financial Mismanagement

Inadequate financial management is another significant reason. Numerous Indian startups collapse due to poor budgeting, overspending, and failure to obtain reliable funding. This predicament is further intensified by India's complicated tax and regulatory frameworks.

Management and Leadership Challenges

Startups frequently experience challenges due to the inexperience and lack of expertise of their founders. Founders who possess insufficient managerial experience may find it difficult to make crucial decisions, which can result in operational inefficiencies and, ultimately, failure.

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Product and Technological Failures: Startups that do not achieve product-market fit are at a heightened risk of failure. Numerous startups in India aim to build technology-heavy products without assessing whether there is genuine market demand for them.

Funding and Investment Issues: Many startups in India, especially within the technology sector, rely extensively on external funding for survival. It has been noted that the absence of dependable investment sources and the challenges in managing investor relations often contribute to the elevated failure rate of these enterprises. Additionally, funding remains one of the major obstacles faced by Indian startups.

Consequences of Startup Failures

The emotional and social consequences of startup failures are extensive and complex. These effects can go beyond financial setbacks and involve a variety of deeply personal influences that affect the entrepreneur's life and relationships.

Financial Losses: Financial setbacks are a clear consequence of startup failure, with entrepreneurs commonly losing their personal savings and encountering the disintegration of their financial resources. These financial challenges can linger long after the business has shut down, impacting future pursuits and creating continued economic strain.

Emotional and Psychological Impact: In addition to financial repercussions, the emotional consequences of failure are significant. Entrepreneurs often undergo grief and emotional turmoil, which can lead to profound psychological effects, such as depress-

ion, anxiety, and social withdrawal. The emotional wounds of failure may last for years and influence personal relationships and future business activities.

Loss of Jobs and Unemployment: Startups are essential sources of employment, especially for young professionals and skilled workers. The failure of startups often leads to large-scale job cuts, contributing to higher unemployment rates and lowering the nation's overall economic productivity.

Reduction in Investment and Innovation: Failed startups also dissuade potential investors from coming into the market, decreasing the availability of venture capital and risk funding for new entrepreneurs. Furthermore, the failure of startups suppresses innovation, as investors become more cautious, and entrepreneurs become reluctant to initiate new ventures.

Stagnation in Startup Growth: Failing startups frequently dissuade new entrepreneurs from entering the ecosystem, resulting in stagnation and diminished vibrancy in the startup community.

Negative Perception of the Startup Ecosystem: The view of high failure rates can foster a negative reputation for the startup ecosystem, making it harder to attract both local and international investors.

Preventive Measures and Strategies to Mitigate Startup Failures

The Indian market presents numerous opportunities for startups that can lead to economic growth and job creation. Nevertheless, despite significant advancements in the ecosystem over the

last twenty years, startups in India still encounter major obstacles. To tackle these challenges, preventive measures should be taken in various areas:

Enhancing the Economic Environment

Startups play a crucial role in the larger economic ecosystem, and enhancements in the general economic environment would significantly benefit them. Investments in both digital and physical infrastructure, like better internet connectivity, upgraded roads, improved public transportation, and dependable electricity supplies, are essential. These improvements would equip startups with the vital resources needed for efficient operation and scaling. Furthermore, a mature economic landscape, characterized by accessible markets and resources, is key to establishing a nurturing environment for startups to flourish.

Improving the Regulatory Framework: Even though the Indian government has rolled out numerous policies aimed at promoting startups, there remains potential for enhancement in their execution. Bureaucratic delays and complicated procedures often obstruct the seamless functioning of startups. Simplifying bureaucracy by minimizing paperwork, enhancing access to information, and standardizing operational processes would greatly alleviate hurdles. For instance, streamlining the process for bidding on government contracts or acquiring licenses would lessen the strain on startups and improve their operational efficiency.

Investing in Education and Talent Development: Allocating resources to education in order to develop

a diverse talent base is critical for nurturing startups. Incorporating entrepreneurship courses into university programs will better prepare students for careers in startups, and fostering entrepreneurial thinking from an early age is vital. Despite a rise in angel and venture capital investments, fledgling startups still grapple with resource limitations, particularly when it comes to funding. Cultivating a talent pool with essential skills will ensure that startups can proficiently execute their ideas, closing the gap between entrepreneurial vision and successful realization.

Addressing the Funding Gap for Early-Stage Startups:

While the funding landscape in India has seen improvements with heightened investments in startups, a gap persists in the early-stage funding sector. Numerous investors tend to concentrate on more established ventures, leaving early-stage startups with scant access to the capital required for prototype creation or market entry. To alleviate this issue, actions such as incentivizing angel investments, eliminating the angel tax, or providing tax incentives to investors could stimulate more financial flow into early-stage startups. The establishment of seed funds and grants to assist early-stage companies is also crucial. Furthermore, promoting acquisitions by larger firms could furnish the financial backing that smaller startups require.

Supporting Startups Outside Metro Cities: The majority of assistance and resources accessible to startups are focused in metropolitan areas, leaving those situated in smaller cities and rural locations at a disadvantage. To equalize the situation, it is essential

ial to extend support to Tier 2, 3, and 4 cities. By expanding the reach of startup hubs throughout India, entrepreneurs in less developed areas will obtain access to resources and networks that are critical for their success. Promoting non-tech startups alongside tech-driven initiatives will diversify innovation in sectors such as manufacturing, retail, and agriculture, creating more opportunities.

Government Policies and Initiatives: The Indian government has launched various initiatives aimed at encouraging entrepreneurship and reducing startup failures. Programs like the StartUp India Scheme provide financial aid, tax benefits, and mentorship opportunities to emerging businesses. These initiatives are designed to lower the obstacles encountered by entrepreneurs, enhancing their prospects for success.

Conclusion

In conclusion, the Indian startup landscape offers a promising yet intricate environment, characterized by considerable growth potential tempered by serious challenges. Although the emergence of startups has been driven by influences such as economic reforms, a large and varied market, and advancing technology, the path to success is still filled with hurdles. The difficulties posed by regional diversity, scaling challenges, and fierce competition, together with the inherent risk of failure associated with disruptive innovation, necessitate that entrepreneurs implement a disciplined, strategic methodology. A crucial element in reducing failure is thorough pre-launch preparation, akin to the detailed

planning done by pilots before taking off. Studies indicate that effective planning, organizing, and strategic communication are vital for navigating the unpredictable startup landscape. Furthermore, support from government entities, investors, and organizations is essential in tackling external issues like infrastructure deficiencies, regulatory environments, and funding limitations. Understanding the reasons behind startup failure in India demands a nuanced approach that acknowledges both internal and external aspects, such as market demand evaluations, strategic planning, and efficient management. Additionally, the impact of external factors, like government regulations and market competition, plays a key role in determining startup success. Ultimately, with the appropriate mix of preparation, strategic implementation and supportive ecosystem frameworks, the survival and success rates of Indian startups can be greatly improved, contributing to the nation's economic growth and its increasing significance in the global entrepreneurial arena.

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Pests and their Management on Ornamental Crops

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Introduction

Horticulturists estimate that 1,500 varieties of herbaceous ornamental plants are grown commercially in North Carolina. Ornamentals are grown in commercial greenhouses, commercial fields, professionally maintained landscapes, interior plants capes, and home grounds, as well as inside homes or in hobby greenhouses. An amazing variety of insects feed on flowering and foliage plants. Many field, fruit, and vegetable crop pests such as the cabbage looper, corn earworm, diamondback moth, and oblique banded leafroller also feed on ornamentals. Lush growth and sheltered growing conditions make ornamental herbs especially attractive to plant pests. Ornamental crops, valued for their aesthetic appeal, are susceptible to a wide range of insect pests. These pests can cause significant damage, reducing the quality and marketability of the crops. These pests feed on various plant parts, including leaves, stems, flowers, and roots, leading to aesthetic damage, reduced Vigor, and even plant death. Effective insect management is crucial for maintaining healthy plants and ensuring profitable yields.

Common Insect Pests

Aphids: These small, sap-sucking insects can cause stunted growth, leaf curling, and the transmission of plant diseases. They secrete honeydew, which can lead to the growth of sooty mold.



Whiteflies: Similar to aphids, whiteflies feed on plant sap and can transmit diseases. They are often found on the undersides of leaves and can be identified by their white, waxy bodies.



Thrips: These tiny insects have fringed wings and feed on plant sap mostly on lower leaf and buds, causing distorted growth and discoloration. They can also transmit viral diseases.



Mealybugs: These soft-bodied insects are covered in a white, waxy substance and feed on plant leaves on base. They can cause stunted growth and leaf drop and also caused leaf dropping.



Scale Insects: These insects have a hard, protective

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covering and feed on plant leaves and floral buds. They can cause yellowing of leaves by sucking their sap, stunted growth, and dieback.



Spider Mites: These tiny arachnids are not insects but can cause similar damage. They feed on plant sap, causing stippling and discoloration of leaves. It is a major pest of marigold and another ornamental plants.



Caterpillars: These are the larval stage of moths and butterflies and can cause significant damage by feeding on leaves and flowers. Its decreases the foliage quality of ornamental crops. Caterpillars can defoliate plants by feeding on leaves.



Leaf Miners: These insects live between the upper and lower surfaces of leaves, feeding on the leaf tissue. They create distinctive tunnels and can cause leaf discoloration and distortion.



Integrated Pest Management (IPM)

IPM is a comprehensive approach to pest management that emphasizes prevention and uses a variety of control methods to minimize pest populations while reducing the risk to humans and the environment. IPM strategies include:

Cultural Control: This involves practices that make the environment less favourable for pests, such as crop rotation, sanitation, and proper watering and

fertilization.

Sanitation: Remove fallen leaves and debris to eliminate breeding grounds for pests.

Watering: Avoid overwatering, as it can create favourable conditions for some pests.

Pruning: Remove infested plant parts to prevent the spread of pests.

Trap cropping

Biological Control: This involves the use of natural enemies, such as predators, parasites, and pathogens, to control pest populations.

Beneficial Insects: Introduce natural predators like ladybugs, lacewings, or parasitic wasps to control pests.

Microbial Control: Use beneficial fungi or bacteria that can infect and kill pests.

Mechanical Control: This involves physical methods of removing or excluding pests, such as handpicking, trapping, and using barriers.

Sustainable Practices

Neem Oil: A natural insecticide derived from the neem tree. It has a broad spectrum of activity and is relatively safe for beneficial insects.

Horticultural Oil: A petroleum-based oil that smothers insects and mites.

Insecticidal Soap: Effective against soft-bodied insects like aphids and mites.

Biopesticides: Pesticides derived from natural sources, such as bacteria, fungi, or viruses. They are generally more environmentally friendly than synthetic pesticides.

Chemical Control: This involves the use of pesti-

des to control pests. However, pesticides should be used judiciously and only, when necessary, as they can have negative impacts on the environment and human health.

Targeted Applications: Use selective insecticides that are specific to the target pest to minimize harm to beneficial insects.

Timing: Apply insecticides when pests are most vulnerable, such as during their early life stages.

Resistance Management: Rotate insecticides with different modes of action to prevent the development of resistance.

Safety Precautions: Always follow the label instructions when using pesticides. Wear appropriate protective clothing and avoid contact with skin and eyes.

Monitoring and Identification

Regular monitoring is essential for early detection of pest problems. This involves inspecting plants for signs of infestation, such as the presence of insects, feeding damage, or disease symptoms. Proper identification of the pest is crucial for selecting the most effective management strategies.

Specific Management Strategies

Aphids: Encourage natural enemies, such as ladybugs and lacewings. Use insecticidal soap or horticultural oil sprays.

Whiteflies: Use yellow sticky traps to capture adults. Apply insecticidal soap or horticultural oil sprays.

Thrips: Use blue sticky traps to capture adults. Apply insecticidal soap or horticultural oil sprays.

Mealybugs: Remove infested plant parts. Use cotton

swabs dipped in rubbing alcohol to remove individual mealybugs.

Scale Insects: Prune heavily infested branches. Apply horticultural oil sprays during the dormant season.

Spider Mites: Increase humidity. Apply miticidal soap or horticultural oil sprays.

Caterpillars: Handpick caterpillars. Use *Bacillus thuringiensis* (Bt) sprays.

Leaf Miners: Remove infested leaves. Apply neem oil sprays.

Conclusion

Effective insect management is essential for the successful cultivation of ornamental crops. By implementing IPM strategies, growers can minimize pest problems while protecting the environment and human health. Regular monitoring, proper identification, and the use of a various control methods are crucial for achieving sustainable pest management. IPM provides a framework for making informed pest control decisions, emphasizing prevention, monitoring, and the use of multiple control tactics. By integrating cultural practices, biological control, and judicious use of chemical control, growers can minimize pest problems while protecting the environment and ensuring the long-term health of their crops. Sustainable practices, such as the use of biopesticides and targeted applications, are crucial for minimizing the impact of pest control on beneficial insects and the environment. Continuous learning and adaptation are key to successful pest management in the dynamic field of ornamental

crop production.

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Implementing a Diverse Framework for Managing Wheat Diseases: An Integrated Approach Incorporating Multiple Strategies

Shyam Narayan Patel, Vikas Yadav and Ashish Kumar Verma

Abstract

A variety of diseases pose a threat to wheat, a crop that is crucial to the world's food security. This synopsis explores a comprehensive approach to managing many wheat diseases, including a range of techniques to increase resistance and lower production losses. Crop rotation, the use of resistant varieties, careful observation for early detection, the cautious use of fungicides, the use of biological control agents, and the improvement of agronomic methods are all important components of an all-encompassing strategy. Combining these tactics creates a comprehensive strategy that aims to reduce the environmental impact of disease control, improve plant health, and interfere with disease cycles. The summary also emphasizes how crucial it is to modify plans according to local conditions, keep an eye on the weather, and carry out educational programs in order to ensure successful implementation. The described framework ensures the long-term productivity and sustainability of wheat agriculture by providing a strong, sustainable paradigm for managing wheat diseases.

Introduction

The cereal crop known as wheat (*Triticum aestivum* L.) is essential to the world's food security. Nonetheless, a variety of diseases that can cause large yield losses and endanger food production continue to cause problems for wheat farmers (Anderson and Patel, 2023). In light of these growing difficulties, the necessity to protect and enhance wheat yields has led to research into diverse disease management strategies. This article explores integrated management strategies, which combine a variety of approaches to address the complex intera-

ctions between different wheat diseases and how they affect agricultural output (Garcia and Kim, 2023). The main goal of integrated disease management is to increase wheat crop resilience by minimizing reliance on separate control strategies and maximizing the efficacy of a cohesive, cooperative strategy. In order to create a strong defense against common wheat diseases, this strategy's complex nature requires the careful integration of cultural, biological, and chemical management techniques (Thompson and Singh, R, 2023). Crop rotation, the adoption of resistant cultiv-

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ars, timely surveillance, and the strategic application of fungicides emerge as crucial components within the integrated management framework as we proceed through our investigation (Khan and Miller, 2023). Recognizing the importance of implementing sustainable practices and tailoring strategies to particular areas, this article seeks to provide insights into the development and implementation of tailored strategies (Patel and Brown, 2023). In order to create a comprehensive and long-lasting strategy for managing wheat illnesses, it also examines the significance of keeping an eye on the weather, doing educational outreach and taking the larger environmental impact into account. By combining these diverse components, the goal is to help create a resilient and sustainable future for wheat farming in the face of the changing problems caused by diseases (Williams and Gupta, 2023). A combination of chemical, cultural, and preventive management methods is required to effectively manage the many diseases that affect wheat. Several strategies for the comprehensive treatment of wheat illnesses are listed below:

Crop Rotation: To break the disease cycle, use crop rotation by alternating the production of non-host crops with wheat. The accumulation of pathogens in the soil is reduced thanks to this method

Resistant Varieties: Wheat cultivars that are resistant or tolerant to common illnesses in your area are ideal. Choose cultivars specifically bred to resist the prevalent illnesses in your area.

Disease-Free Seed: Use certified disease-free seeds

to prevent the introduction of pathogens. It might also be beneficial to apply fungicides to seeds.

Proper Planting Time: To reduce the likelihood of disease development, make sure wheat is sown at the appropriate period. Planting early allows the crop to mature before certain illnesses become more prevalent.

Optimal Plant Density: Follow the recommended plant density to minimize the spread of foliar diseases by promoting efficient air circulation and lowering humidity.

Fertilization and Irrigation: To promote the general health of plants, make sure fertilizer is balanced. Avoid too much nitrogen since it can make plants more vulnerable to some illnesses. To prevent soggy circumstances, adopt suitable irrigation techniques as well.

Monitoring and Early Detection: Check the crop frequently for indications of illness. Efficient detection enables timely action and lessens the effects of illnesses.

Fungicides: Use fungicides as necessary, adhering to disease risk assessments. Utilize fungicides sparingly, making sure that their treatment corresponds with the phases of disease progression.

Biological Control: Investigate the use of biological control agents to reduce disease populations, such as predators or helpful bacteria.

Post-Harvest Practices: Make sure that residue management and other post-harvest procedures are followed correctly to lessen pathogen survivability in between planting seasons.

Integrated Pest Management (IPM): Use an integrated strategy that blends several control techniques. This could involve a mix of chemical, biological, and cultural approaches.

Education and Extension Services: Inform farmers on disease control best management methods. When it comes to sharing knowledge about the newest techniques and technologies, extension services can be really helpful.

Weather Monitoring: Weather conditions should be monitored since some environmental elements can favour certain diseases. In accordance with this, modify management procedures.

Quarantine Measures: Set quarantine procedures in place to stop new or exotic illnesses from entering and spreading throughout your wheat crops.

Conclusion

In conclusion, a potential way to strengthen wheat crops against the ever-changing range of diseases is provided by the integrated management strategies that have been presented. For wheat farming to have a robust and sustainable future, a diversified strategy that incorporates cultural, biological, and chemical control techniques must be adopted. Together, crop rotation, resistant cultivars, careful fungicide use, and attentive monitoring reduce yield losses while fostering long-term environmental and financial viability. As it traverses the fine line between ecological responsibility and productivity, this integrated framework becomes a beacon of hope for safeguarding the world's wheat supplies and guaranteeing food security in the face of

unpredictable agricultural problems. The efficacy of these interventions may differ based on the particular diseases that are prevalent in your area. Support and recommendations tailored to a particular location might be obtained from local agricultural extension agencies.

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Cultivating Success: A Deep Dive into Tomato Farming in Polyhouses

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Abstract

Tomato cultivation in poly houses has revolutionized agriculture, enabling year-round production, overcoming seasonal constraints and significantly boosting yields. Controlled environmental conditions, including optimal temperatures (18-30°C, 16-22°C night for fruit set), high light, and controlled humidity, enhance crop quality and quantity. Seedlings are raised in soil-less media or Vermicompost + sand, germinating in 3-4 days and transplanted at 25-30 days old. Polyhouses primarily use indeterminate hybrids like Syngenta- HimSona and R-144, known for high yield (170 t ha⁻¹) and vertical growth, valued for productivity and quality traits. Techniques such as staking, various training systems, pruning, suckering, topping, fruit pruning, truss hooks, and artificial pollination optimize growth, fruit set, and harvesting efficiency. While mitigating some pests, proactive management is needed for whiteflies, mites, thrips, leaf miners, fruit borers, fungal diseases (powdery mildew, early blight, fusarium wilt), bacterial wilt, and physiological disorders (BER, Russetting, Blotchy Ripening). Harvesting begins 75-85 days post-transplant, with large fruits picked individually and cherry tomatoes in clusters. Proper grading, storage, and packaging maintain freshness. Polyhouse tomato cultivation is a sustainable, profitable method meeting rising market demand for off-season, high-quality produce.

Introduction

Tomato cultivation in poly houses is transforming agriculture, offering significant advantages over traditional open-field methods. This protected environment allows for control over climate, leading to dramatically higher yields, superior quality, and the ability to grow tomatoes year-round, even during challenging seasons. Poly house cultivation boosts India's tomato production potential by combining protected environments with high-yielding hybrids and advanced practices. It's not just about quantity; it

enhances quality and promotes sustainable farming with reduced pesticide use.

Why Protected Cultivation?

Growing tomatoes in poly houses offers compelling benefits:

Better Quality: Controlled conditions minimize exposure to harsh weather, pests, and diseases, resulting in unblemished, high-quality fruits.

Higher Productivity: Optimized climate, nutrition, and plant management lead to significantly increased yields per area.

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Efficient Nursery: Seedlings thrive in a protected environment, ensuring a strong start.

Improved Pest & Disease Control: Physical barriers and controlled humidity reduce outbreaks, lowering pesticide needs.

Off-season Cultivation: Grow tomatoes year-round, accessing profitable off-season markets.

Efficient Resource Use: Drip irrigation and fertigation deliver water and nutrients precisely, minimizing waste.

Greenhouse production allows farmers to supply tomatoes when open-field availability is low, extending the season and fetching better prices. Both spring (Feb-Mar) and fall (Mid-Aug) plantings can be profitable, with spring often yielding more due to increasing natural light.

Climate, Varieties and Nursery

Tomatoes need warmth (18-30°C, 16-22°C at night for fruit set), high light, humidity, soil moisture, and fertilization. Selecting indeterminate hybrids that grow tall (15+ feet) and yield high (170+ t ha⁻¹ over 6-9 months) is key. Consider fruit size, shape, color, shelf life, TSS, disease resistance, and ability to set fruit in varying temperatures. Popular types include Beefsteak, Big fruited, Cluster, and Cherry tomatoes, with specific hybrids like Syngenta- HimSona and R-144 being notable. Nursery raising uses 98-cell trays in a net house or poly house with vermicompost/sand or cocopeat medium. Trays are disinfected and seeds (often treated) are sown one per cell, germinating in 3-4 days. Seedlings are watered, fed, protected from

pests (e.g., thrips), and hardened before transplanting at 25-30 days old (around 16 cm tall).

Preparing Beds and Nourishing Plants

Raised beds are preferred, enriched with organic manure and sand (in heavy soils). Disinfection with formaldehyde and thorough aeration is crucial to eliminate soil-borne pathogens. Neem cake mixed with Trichoderma is also applied for soil health. Basal fertilizers (NPK) are applied before fumigation. Drip irrigation is installed with emitters every 30 cm. Polyethylene mulch film covers the beds to retain moisture, suppress weeds, and maintain soil temperature, with holes for planting. Transplanting 5-6 week old seedlings is done in early morning/late evening after spraying insecticide and drenching with fungicide. Water daily until established; use foggers if humidity is low. Drip irrigation starts 10 days post-transplant, providing 2-3 liters m⁻² day⁻¹. Fertigation delivers water-soluble NPK (e.g., 200:200:200 kg ha⁻¹) twice a week from the third week. Micronutrients and calcium nitrate are also applied periodically. Growth regulators may be used to promote flowering and fruit set.

Guiding Growth: Intercultural Operations

Special practices maximize yield and quality

Staking/Trellising: Support tall plants with poles or wires to keep fruit off the ground, increasing yield and reducing rot.

Training: Guide stems/branches along support (Vertical, Arch, V-shape, S-Hook, Lateral systems) to manage growth.

Pruning: Typically prune to two main stems, remo-

ving excess branches and sometimes fruits for larger size.

Suckering: Remove side shoots (suckers) to direct energy to main stems.

Topping: Remove growing points/small clusters late in the cycle to boost ripening of existing fruit.

Fruit Pruning: Remove small/undersized fruits on clusters for better development of remaining ones.

Truss Hook: Support fruit clusters to prevent bending under weight.

Artificial Pollination: Aid pollination in the enclosed space using bumblebees or vibrators, typically twice daily.

Climate Control, Harvest, and Handling

Maintain optimal climate using evaporative cooling (warm periods, low humidity) and heating (cold periods). Both may be needed for year-round crops. Harvesting begins 75-85 days post-transplant. Large fruits are picked individually with calyx; cherry tomatoes in clusters or singly. Harvest in early morning/late evening in summer. Yields are high (250-300 t ha⁻¹ for big, 150-200 t ha⁻¹ for cherry). Post-harvest, grade tomatoes by size/quality and pack in crates/boxes for transport, maintaining freshness.

Managing Challenges: Pests, Diseases and Disorders

Despite control, issues arise

Pests: Whiteflies, mites, thrips, leaf miners, fruit borers. Control with nets, traps, specific chemicals (dicofol), and soil sterilization (formaldehyde for nematodes).

Diseases: Powdery mildew, early blight, bacterial wilt, fusarium wilt. Control with bleaching powder (bacterial wilt), drenching seedlings with fungicides (bavistin), and foliar sprays (wetttable sulphur).

Disorders: Blossom End Rot (BER - calcium deficiency), Russetting (skin expansion issue), Blotchy Ripening (potassium issue). Manage with proper nutrition (calcium, potassium), consistent watering, and climate control.

The Future

Poly house cultivation is a significant step for tomato farming. It offers higher yields, better quality, extended seasons, and reduced pesticide use. While requiring investment and knowledge, its long-term benefits make it a promising, sustainable path for meeting demand for high-quality, year-round tomatoes.

Nanowarriors: How Nanoparticles are Revolutionizing Crop Protection

Aditee Baruah and Hrishikesh Gogoi

Abstract

Agriculture is facing a crisis- rising pest resistance, soil degradation, excessive chemical use, and climate change threaten global food security. Traditional farming methods, reliant on heavy pesticide and fertilizer applications, are proving to be inefficient, environmentally harmful, and unsustainable. To meet the demands of a growing population while preserving natural resources, agriculture needs a breakthrough this is where nanoparticles (NPs) come in. These tiny, powerful particles are transforming crop protection and nutrient management by offering precision, efficiency, and sustainability. From nano-pesticides that target pests with minimal environmental impact to nano-fertilizers that enhance nutrient uptake, nanotechnology is paving the way for a smarter, greener future in farming. Unlike conventional pesticides and fungicides, NP based formulations enhance the targeted delivery of active ingredients, reducing environmental contamination and minimizing resistance development in pathogens. NPs, such as metal oxides, polymeric carriers, and carbon-based materials, exhibit antimicrobial properties that effectively combat plant diseases while promoting plant health. Additionally, nano-sensors enable early disease detection, allowing timely interventions and reducing crop losses. Despite their immense potential, concerns regarding NP toxicity, regulatory approval, and cost-effectiveness must be addressed for widespread adoption. As research advances, the integration of nanotechnology in crop protection holds promise for transforming agricultural practices, ensuring food security, and fostering sustainable farming systems.

Introduction

Modern agriculture faces numerous challenges in crop protection, threatening global food security and sustainability. Pests, diseases, and weeds continue to evolve resistance against conventional pesticides, making chemical control less effective over time. Excessive pesticide use has also led to environmental contamination, harming beneficial organisms, polluting water sources, and

degrading soil health. Additionally, climate change has intensified these challenges by creating favorable conditions for new pests and diseases to emerge, further complicating crop management. Farmers are caught in a cycle of increasing chemical inputs, rising costs, and diminishing returns, making it clear that traditional methods alone are no longer sufficient. To address these issues, innovative and sustainable solutions, such as nanotechnology, are

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urgently needed to enhance the efficiency and environmental safety of crop protection strategies. Nano-pesticides and nano-fungicides provide targeted delivery systems that increase the effectiveness of agrochemicals while minimizing environmental contamination and pesticide resistance. Nano-fertilizers improve nutrient uptake and reduce wastage, ensuring higher crop yields with fewer inputs. Additionally, nano-sensors enable real-time monitoring of soil health, plant diseases, and nutrient deficiencies, allowing for precise and timely interventions. Certain nanoparticles can also enhance plant resilience by stimulating natural defense mechanisms, helping crops withstand pests, diseases, and environmental stresses like drought and salinity. With controlled-release formulations and eco-friendly properties, nanotechnology offers a sustainable alternative to conventional agricultural methods. While challenges such as cost, regulatory approval, and potential toxicity must be addressed, continued research and innovation can harness nanotechnology's full potential to create a more efficient, productive and environmentally responsible agricultural system.

Understanding Nanoparticles

NPs are tiny particles, ranging from 1 to 100 nanometers in size, with unique properties compared to their bulk counterparts, and can be classified into various types based on their composition and structure. Based on their material composition, nanomaterials can be broadly classified into four main types: carbon-based, metal-based, organic

(including polymers and dendrimers), and composite nanomaterials. NPs in crop protection can act as both direct protectants and carriers for existing pesticides, enhancing their efficacy by improving solubility, penetration, and controlled release, while also reducing toxicity and promoting plant growth and stress tolerance.

Direct Protection and Enhanced Efficacy

Antimicrobial Action: Certain NPs, like metal oxides (ZnO, TiO₂), exhibit antimicrobial properties by inducing oxidative stress, disrupting pathogen cell membranes and organelles, and inhibiting growth and spore germination.

Stress Tolerance: NPs can enhance plant resistance to abiotic stresses (drought, salinity, UV radiation) by increasing antioxidant activities, improving nutrient uptake, and stimulating the expression of stress-responsive genes.

Controlled Release: NPs can encapsulate pesticides, herbicides, and fertilizers, enabling targeted and controlled delivery to crops, maximizing efficacy and minimizing environmental impact.

Nanoparticles as Carriers

Enhanced Pesticide Performance: NPs can act as carriers for existing pesticides, improving their solubility, penetration into plant tissues and stability, leading to better efficacy and reduced degradation.

Reduced Toxicity: By encapsulating pesticides, NPs can reduce their toxicity to non-target organisms and the environment.

Improved Formulation: NPs can enhance the form-

ulation of pesticides, making them more stable and effective, especially in harsh environmental conditions.

Application of Nanoparticles in Crop protection

Managing pathogens is essential to safeguarding agricultural products from diseases that occur both before and after harvest. However, preventing these diseases primarily caused by bacteria, viruses, and fungi remains an ongoing challenge. Inorganic NPs are biocompatible, non-toxic, hydrophilic, and highly stable. Examples include calcium phosphate NPs, gold NPs, iron oxide NPs, zinc oxide NPs, and silver NPs. Inorganic NPs contain ions that act as antimicrobial agents. Zinc and copper promote the generation of reactive oxygen species (ROS), which help eliminate pathogens. Gold and silver are highly toxic to bacteria even at low concentrations.

What does NPs do to prevent attack of pathogen?

- ✓ The use of NPs disrupts pathogen cell membranes and induces the production of ROS, free radicals, and metal ions.
- ✓ A NPs application leads to the generation of reactive oxygen species (ROS) and free radicals and metal ions.
- ✓ NPs of small sizes intercalate into the DNA. Metals are known to bind to thiol or the amine moiety and precipitation of proteins. The high attraction of metal ions by proteins leads to an increase in the cellular concentrations and eventually cell death.

Nanopesticides: Nanopesticides stand for pesticides

formulated in nanomaterials to find applications in the agricultural field, Nanopesticide formulations enhance water solubility and bioavailability while protecting agrochemicals from environmental degradation, transforming the management of pathogens, weeds, and insects in crops. For example, chitosan, a natural biopolymer derived from chitin, is used to create nanopesticides effective against various plant pathogens. These formulations are biodegradable and can induce plant defense mechanisms, offering a dual mode of action. Copper based nanopesticide formulations employ copper nanoparticles known for their antimicrobial properties. They have been used to control fungal and bacterial diseases in crops like grapes and tomatoes. The nano-scale size allows for better adhesion to plant surfaces and improved efficacy at lower concentrations.

Nanofertilizers: Nanofertilizers are nutrient-rich substances enclosed or coated with nanomaterials to facilitate controlled release and gradual diffusion into the soil. Their application helps reduce nutrient loss caused by leaching and runoff while minimizing rapid degradation and volatility, ultimately improving soil fertility and enhancing crop productivity over time. Additionally, due to their high surface area-to-volume ratio and superior penetration ability, nanofertilizers present a promising alternative to conventional chemical fertilizers, offering more efficient nutrient delivery and sustainable agricultural benefits. Nano-biofertilizers (NBFs), a hybrid of nano particle and biofertilizer that produces a

more potent option for eco sustainable agriculture represents an advancement in agricultural innovation.

Nanosensors: Currently, nanosensors are gaining increasing importance in agriculture due to their unique physical and chemical properties. These advanced sensors have significant potential to address agricultural challenges while also contributing to environmental sustainability. In farming, nanosensors play a crucial role in monitoring soil moisture, detecting nutrient levels, identifying insecticides, and recognizing crop pests with high accuracy. Their exceptional sensitivity makes them highly effective for precision agriculture, enabling timely interventions that enhance crop health, optimize resource use, and improve overall productivity.

Challenges and concern

Despite its promising potential, the use of nanotechnology in agriculture comes with several challenges and concerns. One of the primary issues is the uncertainty surrounding the long-term environmental and health impacts of nanoparticles, as their small size and high reactivity could pose risks to soil microbes, beneficial insects, and even human health. Additionally, regulatory frameworks for nano-based agricultural products are still evolving, leading to uncertainties regarding their approval, standardization, and safe application. The high cost of developing and implementing nanotechnology in farming also raises concerns, especially for small-scale farmers who may struggle

with affordability and accessibility. Furthermore, there is a need for extensive research to fully understand the interactions of nanoparticles with plants, soil, and ecosystems to ensure their safe and effective use. Addressing these challenges through strict regulations, cost-effective production methods, and thorough scientific studies will be crucial for the responsible integration of nanotechnology in agriculture.

Conclusion

Nanotechnology is transforming modern agriculture, and nanoparticles are emerging as powerful “nanowarriors” in the battle for effective and sustainable crop protection. By enhancing the precision and efficiency of pesticides, fertilizers, and disease detection systems, nanoparticles offer a revolutionary approach to tackling pests, pathogens, and environmental stressors while minimizing harmful effects on the ecosystem. Their ability to improve nutrient uptake, enable targeted pest control, and support real-time monitoring through nanosensors makes them a game-changer in sustainable farming. However, despite their immense potential, concerns regarding safety, environmental impact, regulatory challenges, and accessibility must be addressed to ensure responsible implementation. With continued research, innovation, and stringent safety measures, nanotechnology can pave the way for a more resilient, productive, and eco-friendly agricultural future, helping farmers protect their crops more efficiently while safeguarding the environment.

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Himalayan Region: The Blessed Zone of Medicinal Fungus

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Introduction

The Himalayan region's unique climatic and ecological conditions, is a treasure trove of biodiversity, including a diverse range of macro fungi, particularly mushrooms and it supports diverse mushrooms importance in traditional medicine and occupy a prominent ecological and ethnopharmacological niches (Sharma *et al.*, 2023; Ullah *et al.*, 2017). Mushroom species like *Cordyceps sinensis*, *Ganoderma lucidum*, and *Morchella* spp. are rich in bioactive compounds and show various pharmacological effects (Vishwakarma *et al.*, 2011). The regular consumption of certain edible mushrooms also contributes to dietary health due to their high content of protein, fiber, vitamins, and minerals. Their nutritional value and traditional uses are well documented across Himachal Pradesh, Uttarakhand, and Azad Jammu & Kashmir (Ali *et al.*, 2023). Many Himalayan mushrooms remain understudied in taxonomy, chemistry and pharmacology, highlighting the urgent need for research amid growing interest in natural remedies. This article aims to present an in-depth review of the major edible and medicinal mushrooms of the Himalayan region such as *Cordyceps sinensis* (Yarsagumba), *Ganoderma lucidum* (Reishi or Lingzhi), *Morchella* spp. (Morel Mushrooms), *Fomitopsis officinalis* (Agarikon), *Trametes versicolor* (Turkey Tail Mushroom), with

emphasis on their ethnobotanical uses, bioactive compounds, therapeutic potential and the importance of sustainable harvesting and conservation.

***Cordyceps sinensis* (Yarsagumba):** *Cordyceps* is a genus comes under Pyrenomycetes, Ascomycotina which is an entomophagous flask fungi in the family Clavicipitaceae. The alpine sub-meadow and grassland habitats of the Himalayan region, particularly the Tibetan Plateau, Nepal, Bhutan, and parts of India are endemic to *Cordyceps sinensis*. It flourishes at high altitudes, typically between 3,000 and 4,000 meters above sea level, where annual precipitation exceeds 350-400 mm (Baral *et al.*, 2015). *Cordyceps sinensis* is called “Yarsagumba” in Nepal, “Dong Chong Xia Cao” in China, and “Keeda Ghass” or “Jeevan Buti” in India, reflecting its cultural and economic value (Anonymous-1). The Tibetan name “yartsa gunbu” (“summer-grass, winter-worm”) describes its dual form: caterpillar in winter and fungus in summer, and it is often locally called “bu” (“worm” or “insect”) (Winkler, 2008). *Cordyceps sinensis* is an entomopathogenic fungus that infects ghost moth larvae (*Thitarodes* spp.). Its spores invade and consume the caterpillar's internal tissues underground, leaving the exoskeleton intact. In spring or early summer, the fungus moves the larva near the soil surface, where a slender, brown, club-shaped fruiting body (8-15 cm long) emerges

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from the caterpillar's head. The moth's reproductive cycle lasts up to five years, mostly as larvae, which the fungus forces to hibernate near the surface while it replaces the larva's internal organs and grows the fruiting body from its head (Winkler, 2008). This fungus contains bioactive compounds such as cordycepin, polysaccharides, sterols, nucleosides, and peptides, which contribute to its medicinal properties including antioxidant activity, anti-inflammatory effects, antitumor and anticancer properties, immunomodulatory effects, renal and hepatic protection, anti-fatigue and energy-boosting effects (Baral *et al.*, 2015). In socio-economic aspects this fungus is considered one of the world's most valuable medicinal fungi often priced above gold, but intense harvesting by Himalayan communities threatens its sustainability and alpine ecosystems. Regulated harvesting and habitat protection are urgently needed to ensure the survival of this unique species (Baral *et al.*, 2015; Anonymous-1).

***Ganoderma lucidum* (Reishi or Lingzhi):**

Ganoderma lucidum is a basidiomycetes white-rot fungus with a global distribution across temperate and subtropical regions, including Asia, Europe, and the Americas and found in mid to high elevations in the Himalayas, majorly cultivated and the natural occurrence are noted in China, Japan, Korea, Vietnam, and parts of Southeast Asia, as well as temperate regions extending to Canada and Argentina. It predominantly grows on deciduous and decaying hardwood trees such as oak, maple, elm, and willow, thriving in warm, humid environments

(Kashyap and Kashyap, 2023). The fruiting body is woody, tough, and reddish in colour, often described as varnished or shiny, which gives it the name "lucidum" (meaning shiny or clear). It has sessile to stipitate basidiocarps with double-walled spores, thick hyphal walls, and grows mainly on hardwood trees (Oke *et al.*, 2022). *G. lucidum* known as the "mushroom of immortality", has been used in traditional Chinese medicine for over 2000 years for its health and longevity benefits (Oke *et al.*, 2022). It contains bioactive compounds such as triterpenoids, polysaccharides, proteins, sterols, alkaloids, and enzymes, which contribute to its pharmacological activities which exhibits immunomodulatory, anti-inflammatory, hepatoprotective (liver protection), antitumor and anticancer properties, antioxidant and free radical scavenging, antimicrobial and antiviral activities (including potential against dengue, enterovirus 71, and COVID-19), neuroprotective and antihistaminic effects, antihypertensive and hypocholesterolemic effects (Oke *et al.*, 2022; El Sheikha, 2022). It is used in various formulations as nutraceuticals, cosmeceuticals, and pharmaceuticals (Oke *et al.*, 2022). To meet global demand, especially in Asia, Europe, Africa, and America, *G. lucidum* is commercially cultivated using intensive technologies on wood logs and sawdust in plastic bags or bottles (Oke *et al.*, 2022). The mushroom is used to produce health supplements, teas, extracts, and functional foods, contributing significantly to the global economy.

***Morchella* spp. (Morel Mushrooms):** *Morchella*

spp. comes under Pezizales order and Ascomycota division. *Morchella* spp. growing predominantly in temperate Northern Hemisphere regions like North America, Europe, Turkey, China, the Himalayas, Pakistan, and India (Himachal Pradesh, Kashmir, Uttarakhand). Yellow morels (*Morchella esculenta*) prefer moist forest floors under deciduous trees such as elm, ash, beech, sycamore, and hickory, while black morels (*Morchella elata*) are found in coniferous forests, disturbed grounds, and recently burned areas. Wild morel mushrooms are locally known as “Gucchi” in Hindi. Morels grow from low elevations (77-616 m) in oak, poplar, and pine forests to high altitudes (1100-2695 m) in temperate mountains; in India’s North-West Himalayas, they occur at 2500-3500 m in Chir Pine and other forests (Soylu, 2024; Verma *et al.*, 2024). Fruiting typically occurs in spring (February to July), but in some regions and species, it can extend to autumn or winter. Morels have a honeycomb-like conical cap on a hollow stem, fruiting singly or in groups near trees or in recently disturbed or burned soils. Some species may have transcontinental distribution and form saprotrophic or facultative mycorrhizal associations. *Morchella* spp. rich in proteins, vitamins, minerals, and antioxidants. They exhibit anti-tumor, anti-oxidation, anti-inflammatory, and immunomodulatory effects (Cao *et al.*, 2022). Traditionally used to boost immunity and reduce oxidative stress and in various cultures for health benefits. As a gourmet edible mushroom, Morels are highly valued with a strong market demand world-

wide, mainly as wild-harvested due to challenging large-scale cultivation. *Morchella esculenta* (Gucchi) is especially valuable in Jammu and Kashmir and Himachal Pradesh, where it grows at high altitudes and supports rural livelihoods through wild harvesting, storage, and marketing.

***Fomitopsis officinalis* (Agarikon):** *Fomitopsis officinalis* predominantly grows in old-growth coniferous forests of the Western Himalayas, from 180 to 2500 meters elevation (Hayova *et al.*, 2020). It forms large, woody perennial bracket fungi on larch, cedar, or pine trunks and branches, often high in the canopy (up to 20 meters or more) (Anonymous-2). The large, hoof-shaped fruiting bodies can exceed 65 cm in length and 40 cm in girth and weigh up to 9 kg. Young conks are soft and yellow-white, hardening with red, brown, or gray cracks as they mature. They release white spores in warm months, taste bitter, smell mild, and cause brown rot by decomposing wood cellulose and hemicellulose (Anonymous-3). *Fomitopsis officinalis* has medicinal properties such as antiviral properties, including activity against respiratory viruses, antimicrobial and anti-inflammatory activities, immunomodulatory effects that may support innate immunity. This fungus is rare and difficult to cultivate, primarily harvested from wild old-growth forests. Its rarity and ecological specificity make it an indicator species for old-growth forest health and biodiversity. The fungus also provides ecological value by creating habitats for wildlife in infected trees (Hayova *et al.*, 2020; Anonymous-3).

***Trametes versicolor* (Turkey Tail Mushroom):**

Trametes versicolor, or Turkey tail, is a saprotrophic white-rot fungus that decomposes lignin in dead hardwoods, occasionally on living trees and rarely on conifers. It grows from lowlands to mountains up to 3,292 m (Peru) and 3,018 m (USA) and is widely distributed across temperate and subtropical regions worldwide, including Europe, Asia, the Americas, and parts of Africa (Srivastava *et al.*, 2024; Hobbs, 2005; Anonymous-4). It is very common in temperate forests and can be found year-round, with fruiting most conspicuous in cooler months when deciduous trees shed leaves (Anonymous-4). The thin, leathery, bracket-shaped fruiting bodies have concentric colour zones (brown, rust, grey, blue, green), flat caps are semicircular to spoon shaped, 4-10 cm wide in overlapping layers, whitish to light brown labyrinthine pore surfaces with 3-8 pores/mm, and cylindrical, smooth white spores. They are tough and inedible when raw, requiring extraction for consumption (Anonymous-4). This mushroom has bioactive compounds such as polysaccharopeptides like PSK (polysaccharide-K) and PSP (polysaccharopeptide) which have immunomodulatory and anticancer properties, β -glucans which enhance natural killer cell activity and antioxidant capacity, Triterpenoids and phenolics which exhibit antiviral (e.g., HIV, HPV), anti-inflammatory, and hepatoprotective effects (Srivastava *et al.*, 2024; Hobbs, 2005; Anonymous-4; Habtemariam, 2020). *Trametes versicolor* has a long history of use in traditional Chinese medicine, known as “Yunzhi”

(Anonymous-4; Habtemariam, 2020). Though tough and inedible as culinary mushroom, this mushroom’s medicinal value supports pharmaceutical and supplement industries, providing income to the rural communities through wild harvesting and cultivation (Hobbs, 2005).

Conclusion

The Himalayan region is a global hotspot for medicinal and edible mushrooms like *Cordyceps sinensis*, *Ganoderma lucidum*, *Morchella* spp., *Fomitopsis officinalis*, and *Trametes versicolor*, valued for their biodiversity and bioactive properties. These mushrooms are integral to Himalayan culture and traditional medicine. Urgent sustainable harvesting, cultivation, and conservation are needed to protect these species for long term. It supports local livelihoods, maintain ecological balance, and advance natural therapeutics.

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Regenerative Agriculture and the Revival of Soil Health

Vineet Kumar, Sushil Kumar Yadav and Vikas Kumar

Abstract

Agriculture is currently confronted by climate change amid ever-increasing needs for food, feed, and other renewable non-food resources threatening its long-term feasibility. People progressively acknowledge that regenerative agriculture works for various environmental and social challenges. It actively rejuvenates ecosystems so it stresses soil vitality, biodiversity, and climate change mitigation, extending beyond mere sustainable practices. For the sake of ecosystems, governments and organizations are investigating the ways that they can incorporate regenerative agriculture into climate action strategies. These efforts are happening from the international level to the local level. This impactful advantage is obtainable without yields being compromised or farmer profits. Soil shapes its properties as an ever-changing living ecosystem harboring a wide array of microorganisms and larger organisms. Helpful physical attributes such as its texture and its water retention do distinguish healthy soil. Important for fostering nutritious as well as profitable crops while improving human health are chemical characteristics like pH along with soil organic matter plus biological features including microbial diversity coupled with soil respiration. Both the public sector and the private sector and the nonprofit sector are drawing attention to regenerative farming with the aim of sustaining both the environment and also improving soil health. Many researchers and non-governmental organizations have sought for to articulate what regenerative agriculture includes and its importance. This review highlights how regenerative agricultural practices can address global warming, enhance soil health, increase biodiversity, and assess its socioecological effects. Looking ahead, additional scientific investigation is needed to explore the impact of regenerative agriculture on both livestock and human health, to foster a healthier community.

Introduction

Regenerative agriculture is changing the face of modern farming by emphasizing methods that improve biodiversity, restore soil health, and support sustainable food systems. The movement's leading

practices, which are transforming agricultural landscapes, include cover crops, no-till farming, and agroforestry. In addition to enhancing soil fertility and structure, these techniques promote microbial diversity, which is essential for disease prevention

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and nutrient cycling. By storing carbon, improving soil water retention, and enhancing plant resistance to pests and diseases, regenerative methods also help to build climate resilience. Soil conservation and regenerative agriculture (RA) are essential strategies for boosting biodiversity, soil fertility and ecosystem health while raising agricultural output and climate change resilience. In addition to addressing environmental deterioration, these sustainable land management techniques support long-term agricultural sustainability.



History of regenerative agriculture

The origins of regenerative agriculture, the terms of “regenerating agriculture” and “regenerative farming” have been grown in the early 1980s after being accepted by the Rodale Institute in the United States. For several ages, the Rodale Institute has commanded the natural agriculture movement through research and publishing, particularly the periodical Organic Horticulture and Farms. During the late 1970s, the term “regenerative” has been linked to agriculture and farming. However, the words “regenerating agriculture” and “regenerative farm” expanded admiration in the early 1980s after being implemented by the US-based Rodale Institute. The Rodale Institute has been at the forerunner of the organic agriculture movement for various years due to its publications and research, which includes the periodical Organic Horticulture and Farms. According to Robert Rodale, regenerative agriculture is

defined as “one that, at higher levels of efficiency, improves our soil's and land's biological resource base,”. In agricultural regeneration, Robert Rodale summaries seven trends viz.

- ✓ Pluralism, which denotes to the multiplicity of plant species.
- ✓ Protection, which highlights the use of cover crops to reduce soil erosion and increase soil surface microbial populations.
- ✓ Purity, which encompasses the intentional absence of fertilizers and pesticides in production.
- ✓ Permanence, which endorses an increase in perennials and plants with strong roots.
- ✓ Peace, which means living in harmony with nature and developing with it rather than opposing it.
- ✓ Potential, which refers to the easily accessible nutrients that rise to the soil's surface and are used by plants.
- ✓ Progress, which includes the constant improvement of soil quality in terms of composition and water-holding capacity.

Importance of Soil Health in Agriculture

Soil health is an essential component of regenerative agriculture as the basis for successful and long-lasting farming systems. Among the many ecological services that healthy soils provide are carbon sequestration, water retention, and nutrient cycling. This section will examine the significance of soil health, going over its makeup, roles, and the dangers that conventional farming practices pose. A dynamic and complex natural resource, soil is made

up of various essential elements such as minerals, organic matter, water, and air.

Soil Degradation and Erosion in Conventional Farming

Traditional farming methods undermine the long-term sustainability and health of the soil by causing substantial soil erosion and degradation, even if they are intended to increase agricultural productivity. These negative consequences are caused in multiple ways by important conventional farming techniques.

Tillage: Tillage improves seedbed preparation and soil aeration at first, it damages soil structure and depletes soil organic matter. Frequent tillage can make the soil thicker and less water-retaining by increasing compaction. The risk of topsoil loss is greatly increased by this disturbance, which also leaves soil vulnerable to wind and water erosion.

Monoculture: Large-scale cultivation of a single crop species diminishes biodiversity and depletes particular nutrients from the soil. Nutrient imbalances can result by repeatedly growing the same species because some crops absorb particular nutrients more quickly than others, depleting the soil of those vital components. Monoculture: When a single crop species is planted over a vast region, biodiversity is decreased and some nutrients are removed from the soil. Nutrient imbalances can result by repeatedly growing the same species because some crops absorb particular nutrients more quickly than others, depleting the soil of those vital components.

Chemical Inputs: Conventional farming heavily relies on synthetic pesticides and fertilizers, which not only reduces the diversity of soil microbes but also contaminates water sources through runoff. Overuse of fertilizers can result in nutrient leaching, which further depletes soil nutrients and exacerbates issues like eutrophication in aquatic environments nearby.



Fig. 2: Source: EOS data analytics

Regenerative Agriculture Practices and Their Impact on Soil Health

The term “regenerative agriculture” refers to a range of methods used to improve and restore soil health while advancing sustainability. This section will go into detail on particular regenerative techniques and look at how they help to increase soil health and the resilience of ecosystems as a whole.

No-Till Farming: As a regenerative agricultural technique, no-till farming entails planting crops without uprooting the soil using traditional tillage techniques. By reducing soil disturbance, this method preserves soil structure and improves a number of soil health indicators.

Cover Cropping and Green Manures: Cover cropping and the use of green manures are essential practices in regenerative agriculture that contribute

significantly to soil health, fertility, and overall ecosystem resilience. These practices involve growing specific crops between main crop cycles or during fallow periods to enhance soil conditions and agricultural productivity.

Crop Rotation and Diversity: Crop rotation is a fundamental technique in regenerative agriculture that entails gradually switching around the kinds of crops cultivated in a given land. In agricultural settings, this method has several advantages that improve biodiversity, reduce soil depletion, and promote soil health.

Agroforestry and Silvi-pasture: Silvi-pasture and agroforestry are innovative techniques that incorporate trees into agricultural systems to improve soil health and advance sustainability. By utilizing trees' ecological advantages, these methods establish a mutually beneficial interaction between crops, livestock, and wooded regions.

Composting and Organic Fertilizers: In regenerative agriculture, composting and the use of organic fertilizers are essential techniques that greatly raise soil nutrient levels and encourage microbial activity, both of which improve soil health overall.

Soil Conservation

Soil Conservation is a combination of practices used to protect the soil from deteriorating. Soil conservation is first and foremost about treating the soil as a living ecosystem. This entails continuously reintroducing organic matter into the soil. The practice of soil conservation is an active, continuous activity that requires the practitioner to

remain dedicated. Learning the fundamentals of the land resource is the first step. Knowing where the soil is most permeable and vulnerable to groundwater pollution from overuse of pesticides, or where the land is most vulnerable to water erosion due to a combination of slope and soil texture, is necessary for this. An adequate conservation strategy cannot be planned without this knowledge. The farmer can prevent soil degradation and increase organic matter by using soil conservation techniques. These include:

- ✓ Crop Rotation is a technique that helps farmers improve the structure, organic matter content, and rooting depth of their soil. By cultivating secondary crops that improve soil health, this is achieved.
- ✓ Cover Cropping and Mulching are good at decreasing soil erosion because they cover the soil, which lessens soil displacement brought on by rains striking soil particles. Additionally, they lessen the amount and speed of runoff across the land.
- ✓ Conservation tillage is a type of field work used to preserve organic matter, soil aggregates, and surface leftovers from past harvests. Conservation tillage may involve modifications like:
 - ✚ Use less damaging tillage tools (such as a chisel plow rather than a moldboard plough)
 - ✚ Less tillage (one pass rather than two)
 - ✚ Timing of tillage (fall to spring)
- ✓ Cross-slope Farming is the practice of performing field work perpendicular to the slope of the

field. This covers the following: tillage and seeding; planting rows of various crops; and diversion terraces. The best technique for managing high runoff volumes that span a long field is cross-slope farming. Cross-slope farming can be successfully combined with other methods of soil conservation.

Conclusion

Regenerative agriculture, in summary, is a game-changing strategy that not only tackles the pressing issues of declining soil health and its conservation but also advances sustainable agricultural methods that are essential for ensuring food security in the face of climate change. The concepts of regenerative agriculture, which include crop rotation, cover crops, no-till farming, agroforestry, and the use of organic fertilizers, provide workable ways to improve soil fertility, restore damaged ecosystems, and encourage a variety of agricultural landscapes. This article's critical analysis of soil health emphasizes how important it is for resilient and productive agricultural systems. Microbial activity and organic matter, which are vital for nutrient cycling, water retention, and general plant health, are abundant in healthy soils. Conventional farming practices degrade soil, endangering ecosystems and the services they offer in addition to reducing agricultural output. By concentrating on improving soil health, regenerative approaches mitigate these problems and promote increased yields while lowering dependency on chemical inputs.

Yellow Mosaic Disease: A Major Threat in Blackgram and Greengram Cultivation in Assam

Ranjana Chakrabarty, Helen Kalita and Priyakshi Buragohain

Abstract

Greengram [*Vigna radiata* (L.) R. Wilczek] and blackgram [*V. mungo* (L.) Hepper] are important pulse crops in India, but their production has faced fluctuations and stagnancy in yields over the last few decades. The productivity remains low due to biotic (Mung bean yellow mosaic virus, web blight, powdery mildew and cercospora leaf spot) and abiotic stresses. Among the various diseases limiting the productivity, Mung bean Yellow Mosaic Virus (MYMV) was given special attention because of its severity and ability to cause yield loss between 10 to 100%, depending on the genotype and stage of crop infection (Nene, 1973).

Introduction

Black gram and greengram are an important short duration legume crop belonging to the family Leguminosae, cultivated for its dry beans rich in proteins with high lysine which is deficient in cereal grains. In India, pulses have long been considered as the poor man's major source of protein. It is an important grain legume with easily digestible protein and low flatulence contents. Black gram grain contains about 25% protein, 56% carbohydrate, 2% fat, 4% minerals and 0.4% vitamins, whereas, greengram contains 24 % protein and is also rich in iron contents (40-70 ppm), making it an ultimate choice for balanced diets. Besides seeds, greengram sprouts, which contain high vitamin C and folate are also very much relished in Asian cuisine. In Assam,

blackgram occupies 58,956 ha with a production of 39,545 t having a productivity of 671 kg ha⁻¹ and greengram occupies 13,553 ha with a production of 10344 t having a productivity of 763 kg ha⁻¹ (Directorate of Economics and Statistics, Assam, 2022-23). In general, these crops are grown in rainfed condition in Assam.

Yellow Mosaic Disease is mainly reported from countries like India, Bangladesh, and Pakistan (Pathak and Jhamaria, 2004; Salam *et al.*, 2011). Among the diseases, Yellow mosaic disease is a destructive viral pathogen that affects the crops, leading to significant yield losses and economic repercussions. The virus poses a major threat to production in Assam, demanding urgent attention and effective management practices.

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Various management approaches have been employed to mitigate the impact of YMV. Considering the yield loss caused by the disease, the symptom, disease cycle and management is discussed for benefit of farming community.

Yellow mosaic disease

Cause: Mungbean Yellow Mosaic Virus (MYMV). It is a Begomovirus belonging to the family geminiviridae.

Symptoms

- ✓ More prevalent in black gram than greengram.
- ✓ Initially mild scattered yellow spots appear on green lamina of young leaves.
- ✓ The trifoliate leaves emerging from the growing apex show irregular yellow and green patches alternating with each other.
- ✓ Spots gradually increase in size and ultimately some leaves turn completely yellow.
- ✓ Plants remain stunted, mature late and produce very few flowers and pods.
- ✓ Early infection causes death of the plant before seed set.

Disease cycle: YMD is transmitted through whitefly (*Bemisia tabaci* Gennadius) under favourable condition. The disease spread by feeding of plants by viruliferous whiteflies. The virus enters the phloem cells of the host through the whitefly proboscis and the viral aggregates appear in the host cell nuclei roughly two days before the symptom appearance. Weed hosts viz., *Croton sparsiflorus*, *Acalypha indica*, *Eclipta alba* and other legume host serve as reservoir for inoculum.



Yellow mosaic disease symptom & infested field

Management

- ✓ Rogue out the infected plants
- ✓ Remove the weed host periodically
- ✓ Grow resistant varieties viz., greengram varieties [SGC 16, IPM 512-1 (Soorya), MH 1142, IPM 02-3, IPM 02-14, IPM 205-7 (Virat)]; blackgram varieties [SBC 40, WBU 109 (Sulata), IPU 02-43, Pant U 31]
- ✓ Install yellow sticky trap @ 12 nos ha⁻¹
- ✓ Spray (2 to 3 times) fipronil 5 SC @ 1.5-2 ml lit⁻¹ of water or lamda-cyhalothrin 5 EC @ 150 -250 ml ha⁻¹, first spray at 10 days after germination and subsequent sprays at 15 days interval based on insect population (Anonymous, 2021).

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Smart Solutions to Stop Food Waste

Arunima V. V., Aathira Rajeevan, Mounika D. and Pooja Ganapathi

Food waste is one of the world's most overlooked problems yet it's happening all around us. From uneaten meals in restaurants to spoiled fruits at home, perfectly edible food ends up in landfills every day. But here's the good news: technology is stepping in with clever, practical solutions that are easy to use and already. Making a huge impact. Whether it's an app, AI, or a natural coating, some of the smartest minds are turning the tide on food waste. Let's explore four powerful innovations that are reshaping the future of food.

Too Good To Go: Turning Leftover into Lucky Finds

An app that helps you buy surplus food from local shops and restaurants at low prices. You order a “surprise bag” from a nearby café or store, pick it up at the end of the day, and enjoy good food that would've been tossed out. It reduces waste, saves money and supports local businesses. Instead of throwing away unsold croissant a bakery sells them in a surprise bag for a third of the price. More people need to download the app, and more food businesses can sign up to offer leftovers instead of wasting them.



A smart system for commercial kitchens that uses AI to track and cut down food waste. Cameras and sensors. Track what food is thrown away, analyze it, and give chefs feedback to plan better and waste less. It helps restaurants and hotels save money while being more sustainable. A hotel kitchen sees they're throwing away too much rice. They adjust their portions, saving thousands each year. More restaurants can adopt this system, and kitchens can train staff to use data to make smarter cooking choices.



IBM Food Trust: Trust through Transparency

A blockchain system that tracks food from farm to fork. Every step of a product's journey is recorded and shared. That means you can trace where your lettuce came from, how it was handled, and when it was delivered. It helps prevent waste by quickly identifying issues and improves trust between producers and consumers. If a batch of spinach is recalled, stores can track exactly where it went and remove only the affected products avoiding mass waste. Encourage more food companies to adopt transparent tracking systems and share data across the chain.

Winnow Solutions: Smart Kitchens that Learn

Arunima V. V. and Aathira Rajeevan

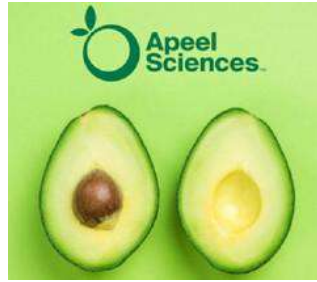
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Apeel Sciences: A Natural Shield for Freshness

A plant-based coating that keeps fruits and veggies fresh longer. Apeel is made from natural food materials and acts like a second skin to slow down spoilage by keeping moisture in and oxygen out. It reduces the amount of food that spoils before it reaches our plate. An Apeel-coated avocado stays ripe for twice as long, giving you more time to enjoy it. Expand its use in more countries and on more types of produce, especially in places without strong cold storage systems.



Conclusion

Solving the global issue of food waste doesn't always require massive overhauls it often begins with simple. Smart solutions powered by technology. From apps that rescue meals to AI in kitchens and invisible coatings that keep produce fresh, these innovations are quietly but. Powerfully transforming the way we handle food. They prove that change is not only possible it's already underway. The next step is in our hands. Whether you're a consumer, a business owner, or just someone who cares about the planet, you can be part of the solution. Download an app, support foodsaving tech, spread awareness, and make conscious choices every day. Because when we waste less, we feed more, save resources, and build a future where food nourishes people not landfills. Together, smart choices can create a smarter, more sustainable world.

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Aeroponics: Soilless Cultivation in Modern Agriculture

R. Sowbarnika, S. Suriya and T. Ilakiya

Abstract

Aeroponics, a relatively new method of producing plants, is becoming more and more popular due to its speed, cost, and novelty. It is a promising soilless farming technique for addressing the future food crisis. Aeroponic farming is a sort of vertical farming and a variation of hydroponics. The Latin terms “aero” (air) and “ponic” (labor) are the roots of the word “aeroponic.” Through this farming, throughout the crop's life, the producer had complete access to the roots and was able to accurately regulate environmental factors, water regimes, and nutrients in the root zone. Superior features of aeroponic farming include superior aeration, efficient use of water, reduced time and space requirements, seasonal independence, disease-free plant growth, and large-scale plant production. Commercial success has been achieved using aeroponic methods for leaf crops, microgreens, tomato production, seed germination, and propagation. Commercial aeroponic systems are used to grow vegetable crops such as potatoes, yams, tomatoes, lettuce, and various green vegetables. In a number of nations, this method has demonstrated some encouraging results and is suggested as the most effective, practical, important, affordable, and convenient technique of growing vegetables.

Introduction

Instead of using soil, crops can be grown in a mist or suspended in the air using a technique called aeroponics, or soilless cultivation. The idea behind aeroponics is the potential to grow vegetables with roots that are placed in containers with flowable plant nutrients rather than in a soil or substratum. Roots can find the ideal moisture and oxygenation conditions in these containers. These circumstances enable more balanced and improved plant nutrition assimilation, which leads to faster development of the cultivated plants. The aeroponic system is easier to use because the plants are kept apart, suspended in the air, and their roots are not submerged in water or soil. Additionally, harvesting of the crops is easy.

It has also been demonstrated that plants cultivated in aeroponic systems absorb more vitamins and minerals, therefore becoming healthier and possibly more nutrient-dense. In order to speed up biomass growth and shorten rooting times, the suspended aeroponic plants receive all of the available oxygen and carbon dioxide to the roots, stems, and leaves. The aeroponic treatment's increased biomass yield of aerial parts suggested that this kind of production should not only be used for root crops but also for other kinds of crops. Aeroponics also allows for higher planting densities because it virtually eliminates competition between plants for water and nutrients. A true aeroponic system can grow any kind of plant because its micro-

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environment can be precisely controlled.

History: Research on aeroponics, a soilless growing technique, started in the 1920s and has since advanced steadily. The technology was mostly employed as a research tool in the early 1940s rather than as a commercially viable crop production technique. The first person to study air culture growing was W. Carter, who in 1942 explained how to use water vapor at the plant's roots to supply nutrients and make root examination easier. In 1944, while studying diseases of the roots of citrus and avocados, L.J. Klotz made the first discovery of vapor-misted citrus plants. Apple trees were cultivated in a spray culture by G.F. Trowel in 1952. In 1983, GTi introduced the Genesis Rooting System, also known as the Genesis Machine, which was the first commercial aeroponics setup. The gadget was just connected to a water faucet and an electrical outlet, and it was controlled by a microchip. NASA conducted a number of experiments in the 1990s both on Earth and in space to grow biomass with very little water and no soil, and the results showed that this approach was highly effective. According to NASA research, plants grown aeroponically have an 80% higher dry weight biomass (important minerals) than plants grown hydroponically. Because a mist is easier to manage than a liquid in a zero-gravity setting, NASA has focused particularly on aeroponic techniques. Fifteen years after Carter's and Went's research, the air-growing method in spray culture was dubbed "aeroponics." Many horticultural and decorative

crops have been produced successfully using aeroponics. In Korea, the aeroponic system has been successfully used to produce potato seed tubers. Aeroponics is being used in agriculture all over the world as of 2006.

Working Methodology: For optimal use of the aeroponic cultivation, the setup consists of an appropriate monitoring and control system for the distribution of water and nutrients. The spray is distributed from a nutrient solution storage tank using a distribution system consisting of pipes, spray nozzles, a pump, and a timer. The roots are sprayed with a fine, high-pressure mist that contains nutrient-rich solutions from the nutrient reservoir in the rooting chamber using a tiny internal micro jet spray. To activate the high-pressure aeroponic pump, a programmable cyclic timer is utilized. Water and nutrients are combined in a reservoir basin, filtered, and then pumped into a pressurized holding tank that is periodically misted on roots. Root hairs that have grown aid in the absorption of nutrients from the moisture. Additionally, it is simpler to deliver various nutrients to the plant through the root system. There is very little nutrient solution waste because the spray particles are tiny. Additionally, root rot is totally prevented with a sufficient supply of oxygen. Around the hung roots, the misting is typically done every few minutes. Normally, the system only briefly activated every two to three minutes. If the misting cycles are stopped, the roots will quickly dry out because they are exposed to the air. Although the aeroponics system requires a brief cycle timer that

runs the pump for a few seconds every couple of minutes, the nutrient pump is controlled by a timer, just like other hydroponic system types. That being said, the chamber needs to be completely lightless in order for the roots to function well in the dark and to prevent the growth of algae, which would hinder the plants' growth and contaminate the system. An important factor in aeroponics is the size of the nutrient mist's droplets. The oxygen supply may be diminished by an oversized droplet. An aeroponic system's efficiency may be impacted by an under-sized droplet that promotes the growth of root hairs while inhibiting lateral root growth. The water droplets need to be large enough to transport enough nutrients to the roots while remaining small enough to avoid precipitating out of the root mass right away. After being strained, filtered, and pumped back into the reservoir, any leftover solution drips down into the unit's base. Aeroponics allows for unrestricted plant growth because there is very little contact between the plant and the support structure.

Nutrients used in aeroponics system: Following is a list of some main nutrients used in aeroponics:

Table 1: Nutrients used in Aeroponics with their concentration

Nutrient	Concentration (g L ⁻¹)
N-NH ₄	0.54
N-NO ₃	0.35
P	0.40
K	0.35
Ca	0.17
Mg	0.08
Fe	0.09
Zn	0.03
B	0.03

Components of Aeroponics

- ✓ Spray misters
- ✓ Droplet size
- ✓ High pressure water pump
- ✓ Light and Temperature
- ✓ Mist frequency
- ✓ Nutrient Reservoir
- ✓ Timer
- ✓ Growing Chambers

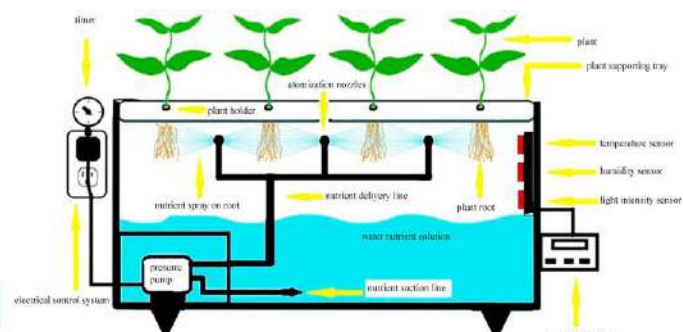


Fig 1: Automated Aeroponics Plant Growing System

Conclusion

Though it is a complex technique, soilless cultures are thought to be a new agricultural development method. In many countries, horticulturists and growers lack the technical knowledge of the new technique, so skilled workers are required. Additionally, most substrates are sold internationally, which drives up their cost. Therefore, it is best to look locally for good substrates that are affordable. Depending on their needs, the location of the system, and their potential financial gain, growers can adjust soilless systems. In any event, the system must closely monitor and maintain the parameters necessary for the plants' healthy growth, including nutrient concentrations, light, oxygen surrounding the root zone, water quality, pH, disinfection, and temperature of solution. Aeroponic systems are the

way of the future because they make crop cultivation easier and help conserve water, land, and nutrients.

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Methods for Assessment of Antifungal and Antibacterial Activities under *In Vitro* Condition

Hirapara Avani and Dinesh H. Chaudhary

Abstract

The control of plant pathogens is essential for sustainable agricultural practices. This article reviews four common *in vitro* methods used to evaluate the efficacy of chemicals, plant extracts and antimicrobial agents against pathogens: 1. Poison Food Method, 2. Dual Culture Method, 3. Agar Well Diffusion Method and 4. Agar Disk Diffusion Method. These methods allow for the assessment of antifungal and antibacterial activities under controlled conditions, enabling precise determination of inhibitory effects.

Introduction

Plant diseases caused by fungal and bacterial pathogens lead to significant crop losses worldwide. Effective management of these pathogens requires precise evaluation of potential control agents. *In vitro* assays provide an efficient and cost-effective means of determining the antimicrobial properties of chemicals, plant extracts and microbial agents. This article explores following different *in vitro* evaluation techniques.

Poison Food Method

This method was developed by Grover and Moore (1962). This method evaluates antifungal activity by incorporating a fungitoxic substance into a nutrient medium. The test fungus is inoculated onto the medium and growth inhibition is measured.

Key materials include: Potato Dextrose Agar (PDA), fungicides and sterile conditions.

Steps to perform Poison Food Method

- ✓ Prepare Potato Dextrose Agar (PDA) by boiling 200 gram of chopped potato in 1 litre of water, filtering and adding 20 gram dextrose and 15 gram agar.
- ✓ Add the desired concentration of fungicide or test substance to the prepared PDA medium.
- ✓ Pour the medium into sterilized petri plates and allow it to solidify.
- ✓ Inoculate the center of each plate with a 5 mm diameter plug of fungal culture.
- ✓ Incubate the plates at 25°C for 7 days.
- ✓ Measure the radial growth of the fungal colony and compare it with the control (without fungicide)

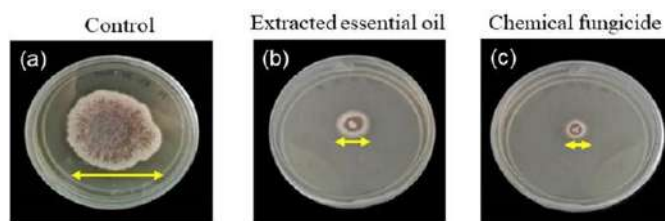


Fig. 1: Poisoned food technique. Effect of treatment

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on colony diameter of tested pathogen growth after 7 days incubation. (a) Treated with sterile distilled water (control), (b) Treated with essential oil extracted from *Coleus aromaticus*; (c) Treated with chemical fungicide

Dual Culture Method

This method assesses the efficacy of bio-control agents against pathogens. Pure cultures of the pathogen and biocontrol agent are inoculated on the same plate. The zone of inhibition between the two cultures indicates the biocontrol potential.

Materials required include: PDA, Cork borers, and Sterilized tools.

Steps to Perform Dual Culture Method

- ✓ Prepare PDA medium and pour it into sterilized petri plates.
- ✓ Inoculate one side of the plate with a 5 mm plug of the pathogen culture and the opposite side with a plug of the biocontrol agent culture.
- ✓ Seal the plates with parafilm or cling wrap to prevent contamination.
- ✓ Incubate the plates at 25°C for 7 days.
- ✓ Measure the inhibition zone or observe interactions between the cultures to evaluate biocontrol activity.



Fig. 2: Dual Culture method showing the antifungal activity *Bacillus firmus* Hussain against Black scurf of Potato (*Rhizoctonia solani*)

Agar Well Diffusion Method

This technique evaluates antimicrobial

activity by creating wells in agar plates filled with test substances. The zone of inhibition around the well indicates antimicrobial efficacy. Factors influencing the results include well size, agent concentration, and medium composition.

Steps to Perform Agar Well Diffusion Method

- ✓ Prepare nutrient agar and pour it into sterilized petri plates.
- ✓ After the medium solidifies, create wells in the agar using a sterilized cork borer.
- ✓ Add 100 μ L of the test substance (e.g., plant extract, antibiotic solution) to each well.
- ✓ Spread the test microorganism (e.g., bacterial culture) evenly over the agar surface using a sterile swab.
- ✓ Incubate the plates at 37°C for 24-48 hours.
- ✓ Measure the diameter of the inhibition zone around each well using a metric ruler.

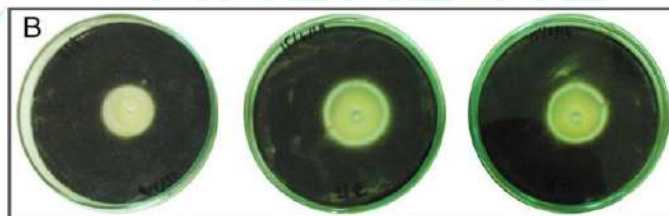


Fig. 3: Agar well diffusion method of essential oil using against *Aspergillus niger* as test micro-organism

Agar Disk Diffusion Method

The Kirby-Bauer method assesses the efficacy of antimicrobial agents using filter paper discs impregnated with test substances. The diameter of the inhibition zone around the disc provides a quantitative measure of antimicrobial activity. This method is widely used for standardizing antibiotic susceptibility tests.

Steps to Perform Agar Disk Diffusion Method

- ✓ Prepare nutrient agar and pour it into sterilized petri plates.
- ✓ Inoculate the agar surface with a standardized microbial suspension using a sterile swab.
- ✓ Place filter paper discs (6 mm diameter) impregnated with the test substance onto the agar surface.
- ✓ Incubate the plates at 37°C for 24-48 hours.
- ✓ Measure the diameter of the inhibition zones around the discs to assess antimicrobial activity.



Fig. 4: Disk diffusion test: Effect of treatment on colony diameter of *Aspergillus niger* growth after 7 days incubation. (d) Treated with sterile distilled water (control); (e) Treated with essential oil extracted from *Coleus aromaticus*; (f) Treated with chemical fungicide

Conclusion

In vitro evaluation methods are essential tools in plant pathology for screening and optimizing disease management strategies. The Poison Food, Dual Culture, Agar Well Diffusion and Agar Disk Diffusion methods provide valuable insights into the efficacy of antimicrobial agents. Future studies should focus on standardizing these methods and exploring their applications in integrated disease management systems.

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From Kitchens to Croplands: How Women-Led SHGs are Cultivating India's Agripreneurial Revolution

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Abstract

Women-led Self-Help Groups (SHGs) have emerged as powerful instruments of socio-economic transformation in rural India. By fostering collective action, these groups empower women to become entrepreneurs, decision-makers, and change agents within their communities. This article explores the role of SHGs in promoting agripreneurship, highlighting their contributions to income generation, skill development, and rural livelihoods. It also examines the challenges faced by women agripreneurs, such as limited access to credit, markets, and technology. Through case studies and policy insights, the paper underscores the importance of supportive ecosystems, capacity building, and government interventions in scaling up the impact of SHGs. The study concludes that women-led SHGs are key drivers of inclusive rural development and sustainable agripreneurship.

Introduction

Rural women hold the key to ending hunger and poverty- Food and Agriculture Organization (FAO, 2023).

Once considered silent contributors behind the scenes, rural women are today emerging as bold change makers, leading India's agricultural transformation from the grassroots. Empowered by Self-Help Groups (SHGs), they are not just earning livelihoods they are building agri-based enterprises, championing sustainable practices, and redefining the rural economy with vision and purpose. Indian agriculture, long characterized by male dominance and traditional roles, is witnessing a quiet revolution. Women, through collective action and microfinance support, are stepping beyond domestic boundaries and into the fields as decision-makers, entrepreneurs,

and leaders. These SHGs are enabling women to access training, credit, technology and markets the building blocks of agripreneurship.

Overcoming the Odds: Challenges Faced by Women Entrepreneurs in Rural India

Despite policy support, women-led SHGs face numerous barriers in their agripreneurial journey:

Limited Access to Credit & Assets: Many SHG members lack collateral or financial literacy to avail institutional loans.

Skill Gaps: Technical know-how in processing, packaging, or marketing is often inadequate.

Market Barriers: Difficulty in accessing markets and competing with established players due to lack of branding or digital skills.

Social and Cultural Constraints: Gender roles,

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mobility restrictions, and family responsibilities limit.

Institutional Support Gaps: Delayed subsidies, insufficient handholding, and bureaucratic hurdles affect enterprise sustainability.

The Journey of Transformation

The Journey of Transformation: From Collectives to Changemakers

Women-led Self Help Groups (SHGs), once seen primarily as thrift and credit institutions, are now transforming into vibrant hubs of innovation, enterprise, and rural development. Moving beyond traditional boundaries, SHG women are stepping into roles as agripreneurs, service providers, and community leaders.

Technology as a Catalyst

Empowered with training and exposure, many SHG members now adopt modern tools and techniques:

- ✓ Mobile-based apps for market rates, weather updates, and agri-advisories.
- ✓ Solar dryers, vermicompost units, and bio-inputs to enhance product quality and shelf life.
- ✓ WhatsApp groups and digital payments to improve coordination and transparency.

These innovations not only improve efficiency but also boost confidence among rural women to manage their enterprises independently.

Branding, Marketing and Value Addition

Unlike traditional producers, SHG-based enterprises now:

- ✓ Develop local brands for items like pickles,

pulses, handicrafts, and herbal products.

- ✓ Tap into niche markets through Geographical Indication (GI) tags and organic certificates.
- ✓ Use digital platforms like Instagram, YouTube, and WhatsApp to reach wider consumers.
- ✓ This shift from mere production to value addition and brand positioning gives them better control over pricing and customer engagement.

Support Systems that Fuel Growth

Their success is not in isolation. A robust ecosystem supports these transitions:

- ✓ NABARD, DAY-NRLM, and State Rural Livelihood Missions offer financial and capacity-building support.
- ✓ Krishi Vigyan Kendras (KVKs) and ATMA projects provide training and technical handholding.
- ✓ Agri-incubators like MANAGE and IITs offer mentorship, packaging ideas, and startup funding
- ✓ E-marketing platforms like e-NAM and ONDC are opening new avenues for rural product.

Together, these efforts pave the way for women to not just participate but lead in India's rural transformation journey.

Case Study Example

Case Study 1: The Milky Way - Moradabad, Uttar Pradesh

Transforming Dairy into a Sustainable Livelihood: In 2016, a group of marginal women farmers from Moradabad, Uttar Pradesh, came together under the Lakshmi Self Help Group (SHG), supported by SPARSH under the NABARD-SHPI

project. Through the Livelihood Enterprise Development Programme (LEDP), they received skill training in dairy farming. With credit support from a local bank Rs. 50,000 in 2017 and Rs. 1.4 lakh in 2019 nine SHG members initiated dairy units and set up a Village Level Collection Centre (VLCC).

Impact: The members' monthly income rose to Rs. 8,340 each, while the price of milk increased from Rs. 3 to Rs. 42 per litre by eliminating middlemen.

Way Forward: The group envisions enhancing milk production, improving cattle breeds, and establishing a service center for animal feed and dairy inputs.

Reflection: This case exemplifies how access to finance and technical training can empower rural women economically through sustainable dairy ventures.

Case Study 2: Ready-Made Success - South Goa, Goa

Apparel Design as a Pathway to Self-Reliance:

In South Goa, 90 women from 21 SHGs received training in tailoring and apparel design under NABARD's LEDP, conducted at AVTI. With a grant of Rs. 5.48 lakh, they established a Common Facility Centre to support production and marketing.

Impact: Several SHG members launched tailoring businesses such as Navdurga Tailoring Shop and Saikunj Creations, generating not only self-employment but also jobs for others.

Way Forward: During the COVID-19 pandemic, they received orders for face masks, showcasing their adaptability. The group now aims to scale up operations to meet growing demand.

Reflection: This case highlights the resilience and creativity of women entrepreneurs in adapting to market needs during crises.

Case Study 3: Handmade Happiness - Morbi, Gujarat

Eco-Friendly Enterprises for Financial Empowerment:

In Morbi, Gujarat, 90 women from 22 SHGs underwent LEDP training in producing eco-friendly garments and handicrafts. With the aid of institutional credit and exposure opportunities, they participated in regional exhibitions like Sahyog Mela and SARAS Fair, collectively earning profits of Rs. 50,000.

Impact: Participation in these fairs enhanced their visibility, market access, and self-confidence.

Way Forward: The SHGs plan to upgrade their design skills and expand their product reach to urban markets.

Reflection: This case illustrates how eco-friendly entrepreneurship can provide a dual benefit sustainable income and environmental responsibility

Case Study 4: Powering Change - Durga Energy, Dungarpur, Rajasthan

Women SHGs Driving Renewable Energy Initiatives:

In Dungarpur, Rajasthan, tribal women from SHGs established Durga Energy, a solar panel manufacturing unit promoted by the Rajasthan Renewable Energy Corporation Limited (RRECL). These women received intensive training in assembling and quality-checking solar panels, under a mission to provide clean energy while generating livelihoods.

Impact: The unit employs over 35 tribal women, producing more than 15,000 solar panels annually. It has enhanced technical skills among rural women and provided consistent income in a non-agricultural sector.

Way Forward: The initiative aims to scale up production capacity and diversify into other renewable energy components.

Reflection: This case highlights the untapped potential of SHGs in non-farm sectors and their role in bridging the gap between rural livelihoods and clean energy goals.

Conclusion

Women-led Self-Help Groups are not just transforming individual lives they are reshaping the rural economy of India. From agriculture to apparel, and dairy to digital platforms, these collectives are creating sustainable livelihoods, building confidence, and fostering local leadership. Despite facing challenges like limited credit, social norms, and market access, their resilience and innovation continue to break barriers. With the right support systems training, financial inclusion, digital tools, and policy backing these women are not just participants in development, but powerful drivers of change. The journey from homemakers to agripreneurs shows that when rural women rise, the entire community prospers.

AI and Machine Learning in Crop Prediction and Yield Optimization

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Abstract

In the era of climate change, global food insecurity, and resource scarcity, artificial intelligence (AI) and machine learning (ML) have emerged as game-changing tools in the field of agriculture. This article explores how AI and ML are revolutionizing crop prediction and yield optimization, transforming traditional farming practices into data-driven smart agriculture. By integrating data from weather forecasts, soil sensors, satellite imagery, and crop management history, these technologies empower farmers with actionable insights for precision farming. The article discusses real-world applications, key algorithms, implementation challenges, and the future scope of AI in sustainable agriculture. The goal is to show how intelligent systems can improve yield prediction accuracy, reduce input costs, and promote sustainable farming at scale.

Introduction: The Need for Smart Farming

Agriculture is the backbone of most economies, especially in developing nations. However, modern-day agriculture faces several unprecedented challenges, including climate unpredictability, population growth, land degradation, water scarcity, and the need for higher food productivity with fewer resources. Traditional farming techniques, reliant on human experience and seasonal patterns, are no longer sufficient. This is where Artificial Intelligence (AI) and Machine Learning (ML) come into play.

These technologies use massive datasets to forecast crop outcomes, automate decision-making, and optimize every aspect of agricultural production from seed selection to harvesting. The integration of AI in agriculture is not just a futuristic concept; it is already being deployed in farms across the globe. This article delves deep into how these tools work and their transformational potential.

Understanding AI and ML in the Agricultural

Context: Artificial Intelligence refers to the ability of machines to perform tasks that typically require

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human intelligence, such as reasoning, learning, and problem-solving. Machine Learning, a subset of AI, involves training machines to learn from data and make predictions or decisions. In agriculture, AI and ML can be applied in several areas such as crop monitoring and health detection, predictive analytics for yield forecasting, soil quality analysis, pest and disease identification, and automated irrigation and fertilization. ML algorithms like Random Forests, Support Vector Machines, Neural Networks, and Gradient Boosting are now routinely used in agronomic modeling.

Sources of Agricultural Data for AI Models:

Accurate crop prediction and optimization require large and diverse datasets. Key data sources include remote sensing data collected via drones and satellites, weather data such as temperature, humidity, rainfall, wind speed, and solar radiation forecasts, soil data including pH, nutrients, moisture, and texture, historical yield data detailing crop performance across seasons, and farmer records noting planting dates, fertilizer use, and pest control methods. All these data points are fed into AI models to generate insights about crop health and projected yields.

Machine Learning Algorithms for Crop Prediction:

There are several commonly used ML models in agriculture. Linear Regression is used for basic yield prediction using numerical data like rainfall and temperature. Random Forest offers high accuracy by creating a forest of decision trees and aggregating their outputs. Support Vector Machines

(SVM) are effective for classifying healthy versus diseased crops based on image and sensor data. Artificial Neural Networks (ANNs) mimic the human brain to detect complex patterns in agricultural data. K-Nearest Neighbors (KNN) classifies crop conditions by comparing with similar historical instances. For example, a Random Forest model can predict wheat yield with more than 90% accuracy based on soil nitrogen levels, rainfall, and seeding rate.

Real-World Applications and Case Studies:

Several startups, governments and research institutions are now applying AI in crop yield optimization. IBM's AI platform uses satellite data, IoT sensors, and weather forecasts to provide tailored farming recommendations. In one project in Kenya, farmers increased maize yield by 30% through AI-guided practices. Microsoft's AI for Earth supports projects that use AI for sustainable agriculture. One initiative in India helped rice farmers determine optimal sowing dates using ML algorithms, resulting in a 10-15% yield increase. Taranis, a company that uses drone-based imagery analyzed by AI, helps detect crop stress, pest infestation, and nutrient deficiencies before symptoms are visible to the naked eye.

Role in Yield Optimization:

Yield optimization does not just mean increasing quantity; it means optimizing inputs to get the best possible output in terms of quality and profitability. AI helps in yield optimization through precision planting by determining ideal planting dates, densities, and row spacing. It supports resource optimization by enabling effici-

ent use of water, fertilizers, and pesticides. It aids in stress detection by identifying drought, pest, or disease stress early. Moreover, AI can predict optimal harvest periods to minimize loss. By analyzing multiple variables, AI can simulate different “what-if” scenarios, helping farmers choose the best practices.

Challenges in Implementation: Despite its promise, integrating AI in agriculture is not without hurdles. Data availability and quality remain major issues, especially in rural areas where inconsistent or missing data can affect model reliability. Cost and access are barriers as smallholder farmers often cannot afford AI tools. There are skill gaps since many farmers may not have the training to use AI platforms effectively. Poor internet and electricity access can disrupt AI deployment. Moreover, if models are trained on limited or skewed data, their predictions may not generalize well. Policymakers need to subsidize AI tools, invest in rural infrastructure, and offer training programs to overcome these barriers.

The Role of IoT, Sensors and Drones: AI becomes even more powerful when combined with complementary technologies. The Internet of Things (IoT) enables real-time monitoring through soil, weather, and crop sensors. Drones provide high-resolution imaging for pest and weed detection. GPS and GIS technologies help in mapping field variability for site-specific treatment. Blockchain ensures secure and transparent traceability in the crop supply chain. For example, a smart irrigation system with soil

moisture sensors can use AI to decide when and how much to irrigate, saving both water and energy.

Policy and Research Directions: To scale AI for agriculture, governments and institutions must create open data repositories for agricultural research. Public-private partnerships in AgriTech innovation need to be promoted. Financial support should be provided for farmers to access AI tools. Building digital literacy in rural communities and funding interdisciplinary research that combines agronomy, data science, and economics are also crucial. Countries like India, Brazil, and Israel have launched national AgriTech missions, showing encouraging signs of progress.

The Future of AI in Sustainable Agriculture: Looking ahead, AI will play a pivotal role in climate-resilient farming by predicting and adapting to extreme weather conditions. It will support carbon farming by monitoring soil carbon to support climate goals. Automated farming systems including self-driving tractors and harvesters guided by AI are on the horizon. AI will also enable genomic prediction by selecting high-yield, climate-resistant crop varieties. In the coming decades, AI will not replace farmers it will empower them with intelligence and foresight that was never before possible.

Conclusion

AI and Machine Learning are no longer luxuries they are necessities for the future of agriculture. From predicting yields to managing inputs efficiently, these technologies hold the key to feeding a growing global population without destro-

ying the planet. The synergy of big data, AI models, and smart farming tools can ensure not just higher productivity, but also sustainability, profitability, and resilience in the agricultural sector. The challenge now is to make these technologies accessible, understandable, and affordable to every farmer, especially the smallholder at the heart of global food systems. The future of agriculture lies not just in the soil, but in the data that grows from it.

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Water Hyacinth as a Potential Biofuel Feedstock Crop

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Abstract

Despite its rampant growth and negative environmental effects, the aquatic perennial water hyacinth (*Eichhornia crassipes*) has drawn some interest as feedstock for biofuel production. This rapidly growing aquatic plant, despite its destructive impact on aquatic ecosystems, has been investigated as a potential biofuel feedstock because of its high biomass yield and abundant biochemical composition. This paper provides an assessment of biofuel production potential from water hyacinth in terms of its growth characteristics, the various methods for conversion to biofuels, environmental benefits and economic viability. Based on the review of existing technologies and their challenges, the authors conclude that water hyacinth provides a renewable energy option with environmental problems related to an invasive species.

Introduction

Water hyacinth (*Eichhornia crassipes*) is a fast-growing aquatic invasive plant species that has established over large areas of the world. Native to South America, it has spread all over the world in lakes, rivers and wetlands and has caused great damage to the environment. Water hyacinth is notorious for its fast-growing nature and high nutrient tolerability that affect many water management agencies across the world. However, it has been studied as a potential feedstock for biofuel production due to its high yield biomass and rapid growth. Biofuels are an attractive renewable energy source because they can contribute to reduce dependence on fossil fuels and climate change. Water hyacinth exhibits fast growth, has high fermentable sugars content, and allows adopting of a number of conversion technologies (fermentation,

anaerobic digestion and pyrolysis), making it an attractive candidate for biofuel production. This paper summarizes the pathways of water hyacinth to biofuels, evaluates its environmental advantages and highlights economic and practical factors involved with using this plant for biofuel production.



Characteristics of Water Hyacinth and Its Growth Potential

Water hyacinth is a free floating perennial aquatic plant with spongy, air-filled roots. They grow larger with bigger bright green leaves along with unique purple flowers. The growth of water hyacinth

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is fast under ideal conditions, with biomass capable of doubling in 5-15 days. It does so at an exceptional rate, which enables it to surpass native aquatic plants and create serious issues like deoxygenation, biodiversity loss, and water blockage.

Chemical Composition and Suitability for Biofuels

Water hyacinth possesses high biomass yield and suitable chemical composition as one of the most potential biofuel feedstocks. Currently, 35-45% of the plant is cellulose; hemicellulose and lignin comprise 20-25% and 15-20% respectively. The importance of these biopolymers is very significant in biofuel production, as cellulose and hemicellulose can be transformed into fermentable sugars; lignin can be recovered for thermochemical conversion to fuels via pyrolysis or gasification. Due to its relatively high content of cellulose and hemicellulose, water hyacinth can be converted into bioethanol. Furthermore, with high moisture content (up to ~95%) of the plant that can further allow for the process of anaerobic digestion, this is another significant biofuel pathway through which biogas could be harnessed from this biomass feedstock source.

Conversion Technologies for Biofuel Production

Depending on the approaches employed, biofuels produced from water hyacinth can possess unique benefits and difficulties. These consist of biochemical methods for bioethanol production, anaerobic digestion for biogas as well as thermochemical methods like pyrolysis and gasification.

Bioethanol Production: Bioethanol, one of the most widely used biofuels, is produced from cellulose-rich materials via a two-step process (pretreatment and subsequent enzymatic hydrolysis and fermentation). Pretreatment of water hyacinth is crucial to disrupt the inflexible cell wall structure and thereby enhancing polysaccharide availability for enzymatic hydrolysis into fermentable sugars. Water hyacinth has been subjected to different methods of pretreatment such as acid hydrolysis, alkaline treatment and steam explosion. Following pretreatment, the sugars are then fermented to ethanol (using yeast or other microorganisms). Water hyacinth can produce 150 to 250 liters of ethanol per ton dry biomass, depending on the process efficiency.

Biogas Production: Anaerobic digestion is a microbial process that generates biogas (mainly methane) from organic waste such as water hyacinth. This technique is uniquely attractive because it represents a cost-effective, scalable technology for using decentralized apparatuses to generate energy. In anaerobic digestion, water hyacinth is decomposed in an oxygen-free environment to produce methane gas that can be used for cooking, electricity production or as fuel for vehicles. A vitro potential biogas production of water hyacinth is $250 \text{ m}^3 \text{ ton}^{-1}$ biomass depending on environmental factors.

Thermochemical Conversion: Pyrolysis and Gasification: Pyrolysis and gasification, for example, are thermochemical processes that produce biofuels from organic material using high temperatures (in the absence of oxygen). Bio-oil, gas

and solid biochar are products obtained from pyrolysis while syngas (a mixture of carbon monoxide, hydrogen and methane) is generated to be used in power generation during gasification. The two processes have been implemented with good bio-oil yields from the water hyacinth. Water hyacinth could yield up to 30% bio-oil through pyrolysis, a valuable product that could be further refined into transportation fuels.

Environmental Benefits of Utilizing Water Hyacinth

The use of water hyacinth for biofuel production could contribute to several environmental benefits:

Management of Invasive Species: Utilization of water hyacinth for bioenergy utilization would mitigate the invasiveness of the species on ecosystems. It can hold back plant that would stifle the waterways and depleting oxygen levels in water bodies, thereby improving water quality.

Wastewater Treatment: Water hyacinth is very good at absorbing eutrophic nutrients including nitrogen and phosphorus, which are known agricultural pollutants of run off. The extraction of water hyacinth from water bodies helps in nutrient control, which improves the quality and rehabilitation of aquatic habitats and mitigates eutrophication.

Carbon Sequestration: Water hyacinth is also a biomass resource and stores carbon, making it a vital carbon sink. As the plant grows, it takes in CO₂; by converting it to biofuels, we get an alternative to putting fossil fuel-based carbon back into the atmosphere.

phere.

Economic Feasibility and Challenges

Water hyacinth has potential as a biomass feedstock for biofuel but its commercialization will rely on many factors. One of the most important points is between cost and location in harvesting, transporting and processing biomass. Although water hyacinth is often plentiful in warmer climates, large-scale harvesting can prove logistically difficult. It grows in dense mats on the surface of the water, and without specialized harvesting, it is nearly impossible to remove from waterways cost-effectively. In addition, fermentation and anaerobic digestion technologies are both infrastructure- and technology-intensive processes. While lingo-cellulosic represent an essentially free raw material, the costs of collection, transportation and conversion may ultimately render them less competitive with other biofuel feedstocks like corn or sugarcane. Nevertheless, its environmental benefits, along with the recent developments in biofuel conversion technologies, may reduce those costs accordingly. If enzyme efficiency is improved and harvesting and processing costs are lowered, then water hyacinth may become a viable feedstock for biofuel production in the future.

Conclusion

Water hyacinth is a potential biofuel feedstock that can serve as a dual purpose both energy-wise and environmental. (Energetic cane) Its fast growth and high biomass yield makes it a strong biofuel candidate as well, since it can be converted

to any of three forms: bioethanol (the most common), biogas, or bio-oil. Using water hyacinth as a biofuel feedstock can alleviate the plants deleterious ecological impacts while producing renewable energy at the same time. However, challenges related to harvesting, processing efficiency, and economic feasibility remain, necessitating further research and technological innovation to unlock its full potential as a sustainable biofuel resource.

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Innovative Approaches to Landscaping with Indigenous Flowering Plants

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Introduction

In the modern era of urbanization and climate change, landscaping has emerged as an essential practice to beautify spaces, conserve biodiversity, and create sustainable environments. While exotic and ornamental species have long dominated landscaping projects, there is a growing shift towards the use of indigenous flowering plants. These native species not only thrive in local conditions but also play a vital role in supporting pollinators, improving soil health, and preserving ecological balance. Innovative landscaping approaches that incorporate indigenous flowering plants are transforming how we design and experience green spaces.

Understanding the Value of Indigenous Flowering Plants

Indigenous flowering plants are species that have evolved in a particular region over centuries, adapting to local climatic conditions, soils, and interactions with native fauna. Unlike exotic species, they require minimal external inputs such as fertilizers and pesticides. They are also naturally resistant to local pests and diseases, making them more sustainable and resilient. Incorporating these plants into landscaping offers numerous benefits. Their deep-root systems help in soil stabilization, reducing erosion and improving water retention. Many indigenous plants have cultural and medicinal

significance, enriching landscapes with heritage value. Most importantly, these plants provide critical habitat and food for native bees, butterflies, and birds, fostering a balanced ecosystem.

Designing Landscapes with Indigenous Flowering Plants

Traditional landscaping practices often focused on manicured lawns and exotic ornamentals. However, innovative approaches prioritize ecological function alongside aesthetic appeal. Here's how indigenous flowering plants are being creatively integrated into landscaping:

Naturalistic Planting Designs: Moving away from rigid geometrical patterns, naturalistic designs mimic the structure and diversity of native plant communities. These designs incorporate clusters of flowering plants that bloom in succession, ensuring color and interest throughout the year. Layering of plant heights, from ground covers to shrubs, creates a dynamic and multi-tiered landscape.

Pollinator Pathways: Landscaping with indigenous flowering plants can create "pollinator pathways" continuous corridors of nectar-rich blooms that support bees, butterflies, and other insects. Strategic placement of flowering species, such as Lantana, Asclepias, and native asters, enhances biodiversity while adding vibrancy to gardens and public spaces.

Rain Gardens and Bioswales: Innovative storm-

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water management systems like rain gardens and bioswales integrate indigenous flowering plants. These installations manage runoff, reduce flooding, and filter pollutants while creating attractive floral displays. Plants like Echinacea, Rudbeckia, and native grasses thrive in these microhabitats, combining functionality with beauty.

Vertical and Rooftop Gardens: Urban landscapes often lack green space at ground level. Vertical gardens and green roofs present an opportunity to incorporate indigenous flowering species in otherwise unused areas. Trailing native plants and climbers bring color and ecological benefits to vertical surfaces, cooling buildings and providing pockets of habitat in dense cities.

Sustainable Maintenance Practices

Innovative landscaping with indigenous plants extends beyond design it encompasses maintenance practices that prioritize sustainability. Native flowering species typically require less irrigation once established, significantly conserving water resources. They also reduce the need for chemical fertilizers and pesticides, minimizing environmental pollution. Seasonal pruning, mulching with organic materials, and promoting natural regeneration of native species contribute to healthy and self-sustaining landscapes. Encouraging community participation in maintenance, such as through community gardens or educational programs, can also foster stewardship and a sense of ownership.

Cultural and Educational Integration

Beyond environmental benefits, landscaping

with indigenous flowering plants offers educational and cultural opportunities. Many native plants hold deep connections to local traditions, folklore, and medicinal uses. Incorporating interpretive signage, art installations or educational trails within landscaped areas can help visitors appreciate the rich cultural significance of these plants. Schools, colleges, and community centers can also leverage these landscapes as outdoor classrooms, teaching about native ecosystems, plant-animal interactions, and conservation efforts. This holistic approach not only beautifies spaces but also nurtures environmental awareness and respect for local flora.

Conclusion

Innovative approaches to landscaping with indigenous flowering plants represent a paradigm shift in how we design and interact with green spaces. By celebrating native species and prioritizing ecological integrity, these practices create landscapes that are not only visually stunning but also environmentally resilient and culturally meaningful. As cities and communities embrace these approaches, indigenous flowering plants will continue to bloom, transforming our landscapes and reconnecting us to the natural heritage of our regions.

Eco-Friendly Landscaping: The Power of Flowering Plants

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Introduction

Landscaping is more than just an aesthetic pursuit—it is a vital component of creating sustainable and eco-friendly environments. In recent years, there has been a growing recognition of the importance of eco-friendly landscaping practices that not only enhance the beauty of outdoor spaces but also support biodiversity, reduce pollution, and conserve natural resources. One of the most effective ways to achieve these goals is through the strategic use of flowering plants.

The Role of Flowering Plants in Eco-Friendly Landscapes

Flowering plants bring vibrant colors, textures, and fragrances to outdoor spaces, but their role extends far beyond visual appeal. These plants play a significant role in creating healthy ecosystems. They attract pollinators like bees, butterflies, and hummingbirds, which are crucial for the reproduction of many plant species. By supporting pollinator populations, flowering plants contribute to food security and the overall health of ecosystems. Additionally, flowering plants help to improve air quality by absorbing carbon dioxide and releasing oxygen. Their root systems help stabilize the soil, reducing erosion and improving soil structure. Many flowering species also provide natural habitat and food sources for birds and small animals, contribut-

ing to a balanced and biodiverse environment.

Choosing the Right Flowering Plants for Eco-Friendly Landscaping

The selection of flowering plants is a critical step in creating an eco-friendly landscape. Native and indigenous species are particularly beneficial because they are adapted to local conditions and require less water, fertilizer, and maintenance compared to exotic species. Native flowering plants are more resilient to local pests and diseases, which minimizes the need for chemical treatments that can harm the environment. When planning an eco-friendly landscape, consider a diverse mix of flowering plants that bloom at different times of the year. This ensures a continuous food source for pollinators and a dynamic, ever-changing landscape that remains visually appealing throughout the seasons. Grouping plants with similar water and sunlight requirements can also improve water efficiency and reduce resource use.

Water Conservation and Soil Health

One of the key principles of eco-friendly landscaping is water conservation. Flowering plants, when selected and placed thoughtfully, can significantly reduce water consumption. Incorporating drought-tolerant species, using mulching techniques, and installing efficient irrigation systems are all practices that support water-wise gardening.

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Healthy soil is the foundation of any successful landscape. Flowering plants contribute to soil health by adding organic matter through leaf litter and decaying plant material. This organic matter improves soil structure, enhances nutrient availability, and promotes beneficial microbial activity. Avoiding synthetic fertilizers and opting for organic soil amendments can further enhance soil health and reduce environmental impact.

Designing with Flowering Plants: Aesthetic and Ecological Benefits

Designing an eco-friendly landscape with flowering plants is an opportunity to combine ecological benefits with artistic expression. Colorful blooms can be used to create focal points, highlight pathways, and define outdoor spaces. Layering plants of varying heights and textures adds depth and visual interest, while also providing different microhabitats for wildlife. Incorporating flowering ground covers can reduce the need for traditional lawns, which often require significant water and chemical inputs. Vertical gardens, green roofs, and living walls are other innovative ways to incorporate flowering plants into urban landscapes, maximizing limited space while supporting biodiversity.

Maintenance and Long-Term Sustainability

An eco-friendly landscape with flowering plants requires thoughtful maintenance to ensure its long-term success. Practices such as composting, mulching, and integrated pest management (IPM) reduce the need for synthetic inputs and promote natural resilience. Regular pruning and deadheading

encourage continuous blooming and prevent the spread of disease. Seasonal care is also essential. In autumn, leaving some seed heads and spent flowers can provide food for birds and winter interest in the garden. In spring, early-blooming flowers offer essential nectar for emerging pollinators. Adopting a holistic approach to garden maintenance supports the health of the entire ecosystem.

Conclusion

Eco-friendly landscaping with flowering plants is a powerful way to create beautiful, sustainable outdoor spaces that benefit both people and the planet. By choosing the right plants, designing thoughtfully and maintaining responsibly, it is possible to transform landscapes into thriving ecosystems that support biodiversity, conserve resources and promote environmental stewardship.

The Art of Flowering Landscapes: Combining Beauty and Functionality

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Introduction

In today's dynamic world, the significance of green spaces in urban and rural environments has never been more critical. Among the myriads of horticultural practices, flowering landscapes stand out for their power to combine aesthetic appeal with practical benefits. The art of flowering landscapes is a deliberate, creative endeavor that blends color, texture, and ecological function to produce spaces that delight the senses while serving essential roles in sustainability and wellbeing.

Aesthetic Harmony and Visual Appeal

Flowering landscapes captivate with their vibrant hues, delicate textures, and dynamic seasonal displays. Thoughtfully curated flowering gardens transform mundane spaces into living works of art. Designers often choose flowers for their colors, shapes, and growth habits to create visual interest and rhythm throughout the seasons. Annuals provide a quick burst of color, while perennials ensure recurring beauty with minimal maintenance. Layering is an essential technique in flowering landscapes, where taller plants provide background structure, mid-sized blooms offer depth, and ground covers fill in gaps, creating a harmonious, layered effect. Color schemes can range from serene monochromes to bold, contrasting palettes, each evoking a different mood and theme. In urban parks, roadside plantings,

and residential gardens alike, flowering landscapes infuse life and vibrancy into concrete and steel environments.

Functionality in Flowering Landscapes

Beyond beauty, flowering landscapes contribute significantly to environmental sustainability and human wellbeing. Carefully selected flowering plants support pollinators, providing essential habitats for bees, butterflies, and birds. They also aid in climate moderation by absorbing carbon dioxide and cooling urban areas through evapotranspiration. Moreover, flowering plants can improve soil health by preventing erosion and enriching soil fertility through natural leaf litter. In addition to ecological benefits, these landscapes promote mental health and relaxation, offering a refuge from the hustle and bustle of modern life.

Designing for Resilience and Sustainability

The art of creating flowering landscapes lies not only in visual composition but also in crafting resilient, low-maintenance ecosystems. Native and adaptive flowering species are increasingly favored for their ability to thrive in local conditions with minimal water and fertilizer inputs. By reducing reliance on artificial irrigation and chemical treatments, these sustainable landscapes help mitigate the negative impacts of traditional landscaping practices. Water-wise gardening, or xeriscaping, is a growing

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trend that integrates drought-tolerant flowering plants, conserving water while still providing striking visual displays. Similarly, integrating rain gardens and bioswales into flowering landscapes can capture and filter stormwater runoff, contributing to healthier watersheds.

Balancing Formal and Informal Styles

Flowering landscapes can take on various design styles, from highly structured formal gardens to more relaxed, naturalistic plantings. Formal gardens often employ symmetrical designs, hedges, and well-defined beds, evoking a sense of order and elegance. These are commonly found in historical estates and public spaces, where they convey a sense of grandeur and tradition. In contrast, naturalistic or wildflower-inspired landscapes embrace organic forms and flowing patterns, mimicking nature's own rhythms. These landscapes celebrate biodiversity and create dynamic scenes that change with the seasons, fostering a deeper connection with the natural world.

Urban Landscapes and Community Wellbeing

In urban environments, flowering landscapes play an important role in enhancing the quality of life. Rooftop gardens, community parks, and greenways filled with seasonal blooms offer city dwellers an oasis of calm amidst the chaos. The psychological benefits of these landscapes are well documented, from reducing stress and anxiety to improving mood and cognitive function. Public spaces adorned with flowering plants also foster social interactions and community pride. Events such

as garden festivals and seasonal flower shows bring people together, strengthening community bonds and encouraging environmental stewardship.

Integrating Functionality with Artistic Vision

The art of flowering landscapes lies in the seamless integration of beauty and utility. Designers and gardeners must consider site conditions, climate, soil health, and user needs to create landscapes that are both visually appealing and functionally robust. Plant selection, soil preparation, and maintenance plans must all work together to ensure longevity and vitality. Equally important is the thoughtful use of hardscape elements such as pathways, seating areas, and water features that complement the floral displays and provide spaces for rest and reflection. Strategic lighting can highlight the colors and forms of flowers, extending their enjoyment into the evening hours.

Conclusion

The art of flowering landscapes is more than a mere arrangement of colorful plants; it is a holistic approach that celebrates nature's splendor while meeting the practical needs of the environment and society. By combining artistry with functionality, flowering landscapes enrich our lives, nurture our planet, and inspire future generations to create spaces of beauty and purpose.

Backyard Gardens to Urban Parks: Floriculture's Impact on Modern Landscapes

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Introduction

Floriculture, the cultivation and management of flowering plants, has evolved beyond the confines of private gardens to become an essential component of urban landscapes. Today, floriculture not only enhances aesthetic appeal but also plays a significant role in improving environmental sustainability, psychological well-being, and urban biodiversity. From quaint backyard gardens to sprawling urban parks, flowering plants have become central to creating spaces that are not only beautiful but also resilient and functional.

The Evolution of Floriculture in Landscaping

Traditionally, floriculture was associated with home gardens and private estates, where ornamental flowers added splashes of color and fragrance. Over the years, however, the discipline has grown to encompass larger-scale applications in public and urban spaces. With the rise of environmental awareness and the push for greener cities, landscape architects and urban planners have embraced floriculture as a vital tool to transform grey cityscapes into vibrant, green oases. The shift from ornamental backyard gardens to expansive public parks illustrates how floriculture has adapted to meet the needs of a changing world. In modern landscapes, flowering plants serve multiple purposes from provid-

ing habitat for pollinators to creating social spaces that foster community engagement.

Floriculture and Environmental Sustainability

One of the most significant contributions of floriculture to modern landscapes is its role in promoting environmental sustainability. Flowering plants act as natural air purifiers, absorbing carbon dioxide and releasing oxygen. In densely populated urban areas, where air quality is often a concern, these plants help mitigate pollution and improve the overall atmosphere. Moreover, floriculture supports biodiversity by providing nectar and habitat for insects, birds, and other wildlife. Incorporating native flowering species into urban landscapes helps conserve local ecosystems and supports the delicate balance between flora and fauna. Floriculture also contributes to water management in urban environments. Thoughtful landscape design, including the use of flowering plants in rain gardens and bioswales helps capture and filter stormwater, reducing runoff and improving water quality.

Enhancing Aesthetic and Recreational Value

Beyond its ecological benefits, floriculture plays a crucial role in enhancing the visual appeal of modern landscapes. Colorful flower beds, seasonal displays and carefully curated plant palettes transform otherwise stark urban environments into

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welcoming and engaging spaces. Backyard gardens, often seen as personal retreats, offer homeowners a chance to express their creativity through floral arrangements and landscape design. These intimate spaces provide not only beauty but also a sense of accomplishment and personal satisfaction. In urban parks and public spaces, flowering plants create inviting environments for recreation and relaxation. Walking paths lined with seasonal blooms, garden installations, and vibrant flower beds encourage people to spend more time outdoors, fostering healthier lifestyles and stronger community bonds.

Psychological and Social Benefits

The impact of floriculture extends beyond the physical environment to touch the mental and emotional well-being of urban residents. Numerous studies have shown that exposure to flowering plants and green spaces reduces stress, improves mood, and enhances cognitive function. The sight and scent of flowers can evoke feelings of joy and calm, offering a much-needed respite from the pressures of urban life. Community gardens and public flower beds also serve as social hubs, bringing together people from diverse backgrounds. Gardening initiatives often promote a sense of ownership and pride, as residents work together to create and maintain beautiful spaces. This shared effort not only strengthens community ties but also encourages environmental stewardship.

Floriculture in Urban Park Design

Modern urban parks increasingly incorporate floriculture principles to create dynamic, multifunct-

ional spaces. Landscape architects and planners use flowering plants to define spaces, guide movement, and create focal points within larger park designs. Seasonal plantings ensure that urban parks offer ever-changing displays of color and texture, enticing visitors to return throughout the year. Carefully selected plant combinations provide continuous blooms, ensuring that parks remain lively and attractive regardless of the season. Moreover, the integration of floriculture in urban park design aligns with the broader goals of creating climate-resilient cities. Drought-tolerant flowering species for example, help reduce water consumption, while pollinator-friendly plants contribute to urban biodiversity.

Backyard Gardens: The Starting Point

While floriculture has transformed public spaces, it remains rooted in the tradition of backyard gardens. These small-scale landscapes are often where people first develop an appreciation for flowering plants and the joys of gardening. Backyard gardens act as laboratories for creativity and experimentation. Homeowners can explore different color schemes, plant combinations, and garden structures, refining their understanding of how flowering plants interact with one another and the broader environment. The lessons learned in backyard gardens often extend to larger community initiatives, as gardeners share their knowledge and inspire others to embrace floriculture. In this way, the humble backyard garden becomes a catalyst for broader change, shaping how communities approach

urban landscaping.

Challenges and Future Directions

Despite its many benefits, integrating floriculture into modern landscapes is not without challenges. Urban environments often present harsh growing conditions, including limited soil quality, water scarcity, and pollution. Selecting resilient flowering species that can thrive in these conditions is essential for long-term success. Furthermore, maintaining flowering landscapes requires careful planning and ongoing care. Urban Park managers and homeowners alike must balance aesthetic goals with practical considerations such as maintenance requirements and resource availability. Looking ahead, the future of floriculture in modern landscapes will likely be shaped by emerging trends such as vertical gardening, green roofs, and sustainable urban farming. Advances in plant breeding and landscape design will open new possibilities for incorporating flowering plants into even the most compact urban spaces.

Conclusion

From private backyard gardens to expansive urban parks, floriculture continues to shape modern landscapes in profound ways. By combining beauty with functionality, flowering plants enrich our cities and our lives, creating spaces that are not only visually appealing but also environmentally sustainable and socially vibrant. As urban areas continue to grow, the role of floriculture in landscape design will become even more crucial, offering a pathway to healthier, greener, and more connected communities.

Exploring the Nutritional Value of Dragon Fruit: A Comprehensive Analysis

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Dragon fruit, with its vibrant colors and unique appearance, is not only visually striking but also a powerhouse of nutrients. This tropical fruit, also known as pitaya or pitahaya, has gained popularity worldwide not only for its refreshing taste but also for its potential health benefits. In this article, we will delve into the nutritional composition of dragon fruit, its health-promoting properties, and how it fits into a balanced diet.

Overview of Dragon Fruit

Dragon fruit belongs to the cactus family and is native to Central and South America, although it is now cultivated in various tropical and subtropical regions worldwide. There are several varieties of dragon fruit, the most common being:

***Hylocereus undatus*:** This variety has red skin with white flesh inside.

***Hylocereus costaricensis*:** Known for its red skin and red flesh inside.

***Hylocereus megalanthus*:** It has yellow skin with white or red flesh inside.

Each variety may differ slightly in taste and nutritional content, but all are generally low in calories and packed with essential nutrients.

Nutritional Composition of Dragon Fruit

Dragon fruit is prized not only for its exotic appearance but also for its impressive nutritional profile. Let's break down the key components that make dragon fruit a nutritious addition to your diet:

Macronutrients

Calories: Dragon fruit is relatively low in calories, making it a suitable option for those watching their calorie intake. One cup (about 227 grams) of dragon fruit typically contains around 60-80 calories, depending on the variety.

Carbohydrates: The majority of the calories in dragon fruit come from carbohydrates. It is a good source of natural sugars, mainly fructose and glucose, which provide a quick source of energy. One cup of dragon fruit contains about 13-18 grams of carbohydrates.

Fiber: Dragon fruit is rich in dietary fiber, which is essential for digestive health. Fiber helps regulate bowel movements, prevents constipation, and may contribute to a feeling of fullness. One cup of dragon fruit provides approximately 3 grams of fiber.

Vitamins

Vitamin C: Dragon fruit is particularly high in vitamin C, also known as ascorbic acid. Vitamin C is an antioxidant that plays a crucial role in boosting the

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immune system, promoting healthy skin, and aiding in wound healing. One cup of dragon fruit can contain up to 9-10 milligrams of vitamin C, which meets about 15% of the daily recommended intake.

Vitamin B₁ (Thiamine): Thiamine is important for converting carbohydrates into energy and supporting proper nerve function. Dragon fruit contains a small amount of thiamine, contributing about 0.1 milligrams per cup.

Vitamin B₂ (Riboflavin): Riboflavin is essential for energy production and metabolism. Dragon fruit provides a small amount of riboflavin, with about 0.1 milligrams per cup.

Vitamin B₃ (Niacin): Niacin plays a role in energy metabolism and is important for maintaining healthy skin and nerve function. Dragon fruit contains niacin, providing approximately 0.5 milligrams per cup.

Vitamin B₆: This vitamin is involved in brain development and function, as well as in the production of neurotransmitters. Dragon fruit contains a small amount of vitamin B₆, contributing about 0.2 milligrams per cup.

Minerals

Calcium: Dragon fruit contains calcium, which is essential for maintaining strong bones and teeth. One cup of dragon fruit provides around 10-15 milligrams of calcium.

Iron: Iron is important for oxygen transport in the blood and for energy metabolism. Dragon fruit contains a small amount of iron, with about 0.4 milligrams per cup.

Magnesium: Magnesium is involved in hundreds of

biochemical reactions in the body, including energy production and muscle function. Dragon fruit contains magnesium, providing approximately 60 milligrams per cup.

Phosphorus: Phosphorus plays a role in bone health and energy metabolism. Dragon fruit contains phosphorus, contributing about 70 milligrams per cup.

Potassium: Potassium is crucial for maintaining fluid balance, regulating blood pressure, and supporting muscle and nerve function. Dragon fruit is a good source of potassium, providing approximately 350-450 milligrams per cup.

Health Benefits of Dragon Fruit

The nutrient-rich composition of dragon fruit contributes to several potential health benefits:

Antioxidant Properties: Dragon fruit is rich in antioxidants, including vitamin C, which helps neutralize free radicals in the body. Antioxidants protect cells from oxidative stress and may reduce the risk of chronic diseases such as heart disease and certain cancers.

Immune System Support: Vitamin C plays a key role in supporting the immune system by stimulating the production of white blood cells, which help defend the body against infections.

Digestive Health: The high fiber content in dragon fruit promotes digestive health by aiding in regular bowel movements and supporting the growth of beneficial gut bacteria.

Heart Health: Potassium and magnesium in dragon fruit contribute to heart health by helping to regulate

blood pressure and maintain proper heart rhythm.

Skin Health: Vitamin C is essential for collagen production, which helps maintain healthy skin, reduce signs of aging, and promote wound healing.

Weight Management: The combination of fiber and low-calorie content in dragon fruit can support weight management by promoting feelings of fullness and aiding in calorie control.

Incorporating Dragon Fruit into Your Diet

Dragon fruit's mild, slightly sweet flavour and refreshing texture make it a versatile ingredient in various culinary applications. Here are some delicious ways to enjoy dragon fruit:

Fresh: Enjoy dragon fruit on its own by cutting it in half and scooping out the flesh with a spoon. Choose ripe fruit with vibrant colour and slightly soft texture.

Smoothies: Blend dragon fruit cubes with other fruits such as bananas, berries, and pineapple for a nutrient-packed smoothie. Add yogurt or almond milk for extra creaminess.

Salads: Add diced dragon fruit to fruit salads or green salads for a pop of color and flavor. It pairs well with citrus fruits, avocados, and leafy greens.

Desserts: Use dragon fruit in desserts like sorbets, fruit tarts, and puddings. Its vibrant color makes it an attractive garnish for cakes and pastries.

Juices and Cocktails: Extract the juice from dragon fruit and enjoy it as a refreshing beverage on its own or mixed with other juices. It also makes a colorful addition to cocktails and mocktails.

Buying and Storing Dragon Fruit

When purchasing dragon fruit, look for fruits

that are brightly colored with firm skin that yields slightly to pressure. Avoid fruits that are overly soft or have blemishes. Dragon fruit can be stored at room temperature for a few days or refrigerated for up to a week. Once cut, store unused portions in an airtight container in the refrigerator and consume within a few days for optimal freshness.

Conclusion

Dragon fruit is not only a feast for the eyes but also a nutritional powerhouse that offers a wide range of health benefits. Whether you're looking to boost your vitamin C intake, support digestive health, or simply enjoy a delicious and refreshing fruit, dragon fruit is a versatile option that can be enjoyed in many ways. Incorporate this exotic fruit into your diet to reap its many nutritional rewards and add a burst of color and flavor to your meals.

Adapting Fruit Cultivation to Climate Change: Strategies to Sustainability and Resilience

Sumit Bura

Climate change poses a profound threat to global agriculture, and fruit cultivation is among the most vulnerable sectors. Rising temperatures, erratic weather patterns, shifting precipitation regimes, and increased frequency of extreme events such as droughts, floods, and storms significantly impact fruit yields, quality, and the geographic distribution of crops. As these challenges intensify, the need for sustainable and resilient strategies in fruit production becomes increasingly urgent. This article explores the key impacts of climate change on fruit cultivation and outlines innovative and adaptive approaches that can help secure the future of this essential agricultural sector.

Impacts of Climate Change on Fruit Cultivation

Fruit crops are highly sensitive to changes in climate due to their perennial nature, long maturation periods, and specific requirements for temperature, chill hours, and water. Some of the major effects of climate change on fruit cultivation include:

Altered Phenology: Warmer temperatures can lead to premature flowering or fruiting, which may not align with the availability of pollinators or favorable weather conditions, thus reducing yields.

Reduced Chill Hours: Many temperate fruit trees such as apples, cherries, and peaches require a specific number of chill hours (exposure to low

temperatures) to break dormancy. Climate warming reduces these hours, affecting bud development and fruit production.

Increased Pest and Disease Pressure: Warmer and more humid conditions create a conducive environment for pests and pathogens to thrive, potentially leading to increased crop losses and higher dependence on chemical controls.

Water Stress: Irregular rainfall patterns and prolonged droughts affect irrigation availability and soil moisture levels, particularly for water-intensive fruits such as citrus, bananas, and grapes.

Extreme Weather Events: Hurricanes, hailstorms, and frosts can destroy entire orchards in a single event, posing a significant risk to growers' livelihoods and market stability.

Strategies for Adaptation and Resilience

To ensure the sustainability of fruit production in the face of climate change, a range of adaptive strategies must be implemented. These strategies should enhance the resilience of both plants and production systems while minimizing environmental impacts.

Climate-Smart Cultivar Selection

Developing and adopting fruit varieties that are tolerant to heat, drought, and disease is a critical step in adaptation. Breeding programs must focus on:

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Heat-tolerant varieties: Selecting cultivars that can perform well under higher temperatures without compromising fruit quality.

Low-chill varieties: Introducing fruit tree cultivars that require fewer chill hours for successful flowering and fruiting.

Disease-resistant strains: Utilizing traditional breeding, marker-assisted selection, and genetic modification to produce varieties resistant to emerging pests and diseases.

Agroecological and Biodiverse Systems

Increasing biodiversity within orchards can enhance ecosystem resilience and reduce vulnerability to climate extremes:

Intercropping and agroforestry: Integrating fruit trees with other crops and trees improves microclimates, conserves water, and reduces pest pressure.

Pollinator-friendly practices: Enhancing habitat diversity to support native pollinators helps ensure successful fruit set.

Cover cropping and mulching: These practices improve soil health, retain moisture, and reduce erosion.

Efficient Water Management

Water scarcity is a critical concern, and efficient water use is essential:

Drip irrigation: This technology delivers water directly to the root zone, minimizing losses and improving water use efficiency.

Rainwater harvesting: Capturing and storing rainfall provides a buffer during dry spells.

Soil moisture monitoring: Sensors and remote

monitoring tools help optimize irrigation timing and amount.

Precision Agriculture and Digital Tools

Digital technologies provide powerful tools to monitor, predict, and respond to climatic risks:

Remote sensing and GIS: Satellite imagery helps track crop health, soil moisture, and pest outbreaks.

Climate modeling and forecasting: Access to localized climate predictions allows growers to make proactive decisions.

Decision support systems (DSS): Integrating data from various sources to inform actions such as irrigation scheduling, pest management, and harvest planning.

Resilient Orchard Design and Management

Designing orchards to withstand climatic extremes is vital:

Windbreaks and shade nets: Protecting trees from heat and wind stress can reduce damage and improve microclimates.

Diversification of varieties and rootstocks: Planting different cultivars and using resilient rootstocks can spread risk and enhance overall orchard stability.

Replanting strategies: Rotating tree plantings and rejuvenating old orchards can sustain productivity in changing climates.

Post-Harvest Innovation and Supply Chain Resilience

Adapting to climate change doesn't end at harvest:

Cold storage and transport innovations: Reducing post-harvest losses through improved storage and

transport systems ensures profitability even when yields are variable.

Local and regional markets: Strengthening shorter supply chains reduces exposure to global disruptions and fosters community-based resilience.

Value addition: Processing fruits into juices, jams, or dried products can stabilize income in years of surplus and scarcity alike.

Policy Support and Capacity Building

Technical solutions must be supported by enabling policies and capacity-building initiatives:

Research and development (R&D): Public and private investment in R&D is essential to develop and disseminate climate-resilient practices and technologies.

Extension services: Farmers need access to timely information, training, and support to implement adaptive strategies effectively.

Insurance schemes: Weather-based insurance can cushion growers against financial losses due to extreme events.

Subsidies and incentives: Governments can encourage sustainable practices through subsidies for drip irrigation, organic inputs, and renewable energy.

Conclusion

Adapting fruit cultivation to climate change is not just a challenge it is an opportunity to transform agricultural systems into more sustainable, diversified, and resilient enterprises. By combining traditional knowledge with modern technology, investing in research and education, and aligning policy with ecological principles, the fruit-growing

sector can thrive even in an uncertain climate future. The time to act is now, and with coordinated efforts from farmers, scientists, policymakers and consumers, we can secure the future of fruit cultivation for generations to come.

Smart Orchards: How AI and IoT are Transforming Fruit Production

Sumit Bura

The global fruit industry is facing unprecedented challenges due to climate change, labor shortages, rising costs and the demand for sustainable farming. In response, technology is reshaping traditional orchard management. Artificial Intelligence (AI) and the Internet of Things (IoT) are driving this transformation, giving rise to smart orchards digitally connected farms that use real-time data and automation to optimize every stage of fruit production. Smart orchards rely on advanced technologies such as sensor-based monitoring, AI-driven yield prediction, automated pest detection, and robotic automation. Together, these tools offer a data-driven, precise, and efficient way to grow fruit, helping producers increase productivity, reduce input use, and adapt to changing environmental conditions.

Sensor-Based Monitoring: Real-Time Insight into Orchard Health

At the core of every smart orchard is a network of IoT-enabled sensors that gather continuous data on critical environmental and plant parameters. These include:

Soil moisture sensors: Help regulate irrigation by tracking real-time water availability in the root zone.

Temperature and humidity sensors: Monitor microclimate conditions, which affect flowering, fruit development, and disease risk.

Leaf wetness sensors: Detect surface moisture

levels, aiding in the prediction of fungal diseases like powdery mildew or apple scab.

Canopy and light sensors: Provide insights into plant growth, photosynthetic activity, and fruit exposure to sunlight.

By connecting these sensors to a cloud-based dashboard, growers can monitor conditions remotely and receive alerts for deviations, helping them take timely and targeted actions. This approach not only conserves water and inputs but also protects crop health throughout the growing season.

Yield Prediction: AI-Driven Forecasting for Smarter Decisions

Accurate yield estimation is crucial for effective planning, from labor management to logistics and market supply. Traditionally, yield forecasts were based on manual counting or historical averages, but these methods often lacked precision. Today, AI algorithms, combined with computer vision and remote sensing, provide much more accurate and early yield predictions.

Drones and high-resolution imagery: Capture data on blossom density, fruit counts, and canopy vigor.

Machine learning models: Analyze historical data, weather patterns, and sensor inputs to forecast yields under different conditions.

On-the-ground imaging tools: Mounted on tractors or handheld devices, these tools scan trees to assess

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fruit size, color, and ripeness.

With precise yield predictions, growers can better allocate labor, optimize harvest timing, and plan distribution. This minimizes post-harvest losses and improves the profitability of operations.

Pest Detection: Early Warnings through AI and Sensors

Pest outbreaks and plant diseases are among the biggest threats to fruit production. Traditional scouting methods can be time-consuming and reactive. In contrast, smart orchards employ AI-powered pest detection to spot problems before they escalate. Key innovations include:

Camera traps with AI analysis: These smart traps identify and count specific pests, such as codling moths or fruit flies, sending real-time data to growers.

Computer vision: AI models analyze images of leaves and fruit to detect early signs of damage, discoloration, or deformities.

Predictive analytics: Combine sensor data (humidity, temperature, wind) with pest behavior models to anticipate infestations before they occur.

This technology enables precision pest management targeted spraying only when and where it's needed-reducing chemical use, costs, and environmental impact.

Automation: Robotics and AI in Orchard Operations

One of the most revolutionary aspects of smart orchards is automation. Robotics and AI are now capable of performing labor-intensive tasks

with speed and accuracy, alleviating the pressure of labor shortages and improving consistency.

Examples of orchard automation include:

Autonomous harvesters: Use AI vision to identify ripe fruit and robotic arms to harvest without damaging the crop.

Self-driving sprayers and mowers: Navigate rows of trees, performing tasks like weeding or spraying with precision and minimal human input.

Automated pruning and thinning machines: Use AI to analyze tree structures and remove unnecessary growth for improved fruit quality.

These machines not only save time and labor costs but also collect data during operation, further contributing to the orchard's digital ecosystem.

The Benefits of Smart Orchards

Adopting smart orchard technology offers multiple advantages:

Higher efficiency: Reduce water, chemical, and labor usage through precision farming.

Improved fruit quality: Monitor and respond to plant needs more effectively.

Greater sustainability: Use fewer inputs and lower emissions while enhancing soil and plant health.

Better decision-making: Use real-time data and predictive analytics to stay ahead of problems and optimize operations.

Challenges and the Road Ahead

Despite the promise of smart orchards, there are still challenges to overcome:

Initial costs: Setting up sensor networks and automation systems can be expensive.

Connectivity: Remote orchards may lack stable internet, limiting the functionality of real-time systems.

Data integration: Managing and interpreting large volumes of data requires training and technical support.

However, as technology advances and becomes more affordable, these barriers are gradually lowering. Government incentives, research programs, and agri-tech startups are playing a key role in accelerating adoption.

Conclusion

Smart orchards represent a bold step toward the future of fruit farming. By integrating sensor-based monitoring, AI-driven yield prediction, automated pest detection, and advanced automation, growers can transform traditional practices into highly efficient, data-driven systems. These innovations not only increase productivity and profitability but also contribute to more sustainable and resilient agricultural landscapes.

As the global demand for high-quality fruit continues to rise, the adoption of AI and IoT technologies in orchards will become not just an advantage but a necessity. The future of fruit production is smart, connected, and ready to meet the challenges ahead.

Mechanization in Fruit Crops: Transforming Orchards for the Future of Agriculture

Sumit Bura and Hansraj Yadav

As the global population steadily climbs and food security becomes increasingly urgent, the agricultural sector is under pressure to produce more with fewer resources. Among the most demanding areas of cultivation is fruit farming - a sector characterized by high labour dependency, intensive care, and delicate handling. In recent years, however, a quiet transformation has been taking place: mechanization is reshaping the way fruit crops are cultivated, maintained, and harvested, ushering in a new era of precision and productivity. Traditionally resistant to mechanization due to the sensitive nature of fruits and the complexity of orchard layouts, the sector is now embracing technological innovation. From GPS-enabled tractors to robotic harvesters, machines are stepping in to enhance efficiency, reduce dependency on labor, and meet the challenges posed by climate change, rising input costs, and growing consumer expectations for quality and consistency.

The Growing Need for Mechanization in Fruit Farming

Fruit production is inherently more labour-intensive than staple crops like wheat or corn. Orchard management includes a series of complex

tasks such as pruning, thinning, fertilizing, spraying, and harvesting many of which require timing, precision, and a gentle touch. Historically, these tasks have relied heavily on manual labour, but this model is becoming increasingly unsustainable. In many parts of the world, fruit growers are grappling with labor shortages, rising wages, and stricter labour regulations. At the same time, consumers demand year-round availability of high-quality fruits, often sourced from regions struggling with changing climate conditions. Mechanization addresses these challenges by improving consistency, reducing reliance on seasonal labor, and increasing the scalability of operations.

Key Mechanized Operations in Fruit Crop Production

Land Preparation and Orchard Establishment:

Mechanization begins at the foundation - preparing the land and establishing the orchard. Modern tractors, often equipped with GPS and auto-steering systems, can perform ploughing, levelling, and soil preparation with unmatched accuracy. Specialized planters ensure that saplings are spaced precisely, facilitating uniform tree growth and future compatibility with mechanized pruning and harvesting

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equipment.

Pruning and Canopy Management: Pruning plays a critical role in determining fruit yield, size, and quality. Mechanical pruners, which may be tractor-mounted or handheld, use rotating saws or blades to trim branches efficiently. These machines reduce the labour time by over 60% in many cases and promote uniform canopy structure, which improves sunlight penetration and reduces disease incidence.

Spraying and Fertigation Systems: Crop protection is another labour-heavy aspect of fruit farming. Today's sprayers, often automated or drone-operated, use variable-rate technology and sensors to apply pesticides or fungicides precisely where needed, reducing chemical usage and environmental impact. Likewise, fertigation systems automated units that apply fertilizers through irrigation enable precision nutrient management based on real-time data about soil and plant health.

Fruit Thinning: Thinning is essential in crops like apples and peaches to prevent overcrowding and ensure that the remaining fruits grow to optimal size and quality. Mechanical thinners, such as string thinners or rotary blossom thinners, can efficiently remove excess fruits or blossoms. These machines not only reduce the labour involved but also improve yield uniformity across the orchard.

Harvesting Innovations: Harvesting remains the most challenging aspect of fruit mechanization, especially for delicate fruits that bruise easily. Nevertheless, progress is being made. For fruits like grapes, olives, and citrus, large-scale mechanical

harvesters have been used successfully for years. For softer fruits, innovations in soft-touch robotics, AI-powered vision systems, and gentle suction or gripper mechanisms are making selective harvesting increasingly viable. Semi-automated harvesting platforms are also gaining popularity, where human pickers are assisted by conveyor belts, mobile platforms, and data-guided tools that increase their efficiency and comfort during long harvest hours.

Post-Harvest Sorting and Packing: Mechanization doesn't stop at harvest. Post-harvest technologies such as optical sorters, automated washers, and packing lines now allow for rapid grading, cleaning, and packaging of fruits. These systems can detect bruises, colour variation, size discrepancies, and even internal defects using infrared imaging, ensuring that only the best-quality fruit reaches consumers.

The Benefits of Mechanization

The advantages of mechanization in fruit crops go far beyond labour savings:

Increased Operational Efficiency: Machines can complete time-sensitive tasks faster and more consistently than human labourers.

Cost Savings Over Time: Though initial investments may be high, mechanized systems reduce long-term labour and input costs while minimizing losses from delays.

Enhanced Fruit Quality: Precision in operations like thinning, pruning, and spraying directly impacts fruit size, taste, and shelf-life.

Environmental Sustainability: Mechanization sup-

ports responsible agriculture by reducing water use, limiting chemical inputs, and enabling site-specific management that lessens environmental stress.

Resilience to Labour Shortages: With fewer people willing or able to work in physically demanding farm jobs, mechanization provides a much-needed alternative.

Challenges and Considerations

Despite its promise, mechanization faces several roadblocks. The cost of high-tech equipment is often prohibitive, especially for small and medium-scale farmers. Many machines require trained operators and regular maintenance. Moreover, not all fruit crops are easily mechanized -trees with irregular canopies or fruits that grow in clusters still pose technical challenges. Another critical issue is terrain. Sloped or uneven orchards, common in hilly fruit-growing regions, can be difficult to navigate with large machinery. However, research into lighter, more agile machines is beginning to address this gap. To facilitate widespread adoption, stakeholders including governments, agro-tech companies and academic institutions must collaborate. Initiatives such as subsidies, cooperative machinery banks, and training programs can make mechanization accessible and sustainable for growers across diverse regions.

Conclusion: A Mechanized Future for Fruit Farming

Mechanization is no longer an option but a necessity in the evolution of fruit farming. It holds the key to overcoming labour shortages, ensuring

consistency in quality, and scaling up operations to meet global demand. As technologies advance and become more tailored to specific crops and farm conditions, mechanization will become increasingly feasible and affordable. The integration of smart machines with data analytics, AI, and automation marks the next frontier. With thoughtful implementation and support, mechanized fruit farming can pave the way toward a more productive, resilient, and environmentally responsible agricultural future.

Integrated Nutrient Management (INM) in Fruits: A Sustainable Approach to Boost Productivity and Quality

Sumit Bura, Amit Jasrotia and Arti Sharma

Introduction

The increasing global demand for fruits, driven by health-conscious consumers and rising incomes, has made horticulture a vital sector in agriculture. However, intensive fruit cultivation has often led to the overuse of chemical fertilizers, degrading soil health and reducing long-term productivity. To combat this, Integrated Nutrient Management (INM) has emerged as a sustainable and holistic approach to improving fruit yield and quality while maintaining soil fertility. INM involves the judicious use of chemical fertilizers, organic manures, biofertilizers, and other amendments in a scientifically balanced manner. This ensures the optimal supply of nutrients to crops without compromising soil and environmental health.

The Need for INM in Fruit Cultivation

Fruit crops, unlike annual crops, have longer life cycles and require consistent nutrient supply across multiple years. Traditional farming practices often rely heavily on chemical fertilizers to meet the nutritional demands of fruit plants. While this boosts short-term yield, it can cause long-term issues such as:

- ✓ Soil degradation (loss of organic matter, compaction, erosion).

- ✓ Nutrient imbalance and micronutrient deficiencies.
- ✓ Decline in fruit quality.
- ✓ Environmental pollution, particularly nitrogen and phosphorus leaching into water bodies.
- ✓ Increased cost of production due to inefficient nutrient use.

INM offers a solution by integrating all nutrient sources in an efficient, economic, and environmentally safe manner.

Components of Integrated Nutrient Management in Fruits

Chemical Fertilizers

- ✓ Provide immediate nutrient availability, especially nitrogen (N), phosphorus (P), and potassium (K), which are essential for fruit development.
- ✓ INM encourages precise application based on soil testing and crop requirements to avoid excesses or deficiencies.

Organic Manures

- ✓ Includes farmyard manure (FYM), compost, vermicompost, green manure, and crop residues.
- ✓ Improve soil structure, enhance microbial activity, and increase water-holding capacity.
- ✓ Release nutrients slowly, supporting long-term soil fertility.

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Biofertilizers

- ✓ Microorganisms like Azotobacter, Azospirillum, Rhizobium, Phosphobacteria, and mycorrhizal fungi are used to fix atmospheric nitrogen, solubilize phosphorus, and improve nutrient uptake.
- ✓ Enhance root growth and resilience against biotic and abiotic stress.

Soil Amendments

- ✓ Substances like lime, gypsum and dolomite correct soil pH and improve nutrient availability.
- ✓ Particularly important in acidic or saline soils common in many fruit-growing regions.

Crop Residue Recycling

- ✓ Incorporating pruned branches and fallen leaves into the soil adds organic matter and recycles nutrients.

Foliar Nutrition

- ✓ Foliar sprays of micronutrients like zinc, boron, and iron help in correcting deficiencies during critical growth stages.

Benefits of INM in Fruit Crops

Enhanced Yield and Quality

- ✓ Balanced nutrition results in better fruit size, color, taste, and shelf life.
- ✓ Reduces physiological disorders like fruit cracking, spongy tissue, and internal breakdown.

Improved Soil Fertility

- ✓ Organic and biological inputs increase soil microbial diversity and activity.
- ✓ Maintains or enhances soil organic carbon levels.

Environmental Sustainability

- ✓ Reduces chemical runoff and groundwater pollution.
- ✓ Encourages carbon sequestration through organic matter addition.

Cost-Effectiveness

- ✓ Reduces dependency on costly chemical inputs.
- ✓ Promotes use of locally available resources (e.g., cow dung, compost).

Resilience to Climate Change

- ✓ Improves soil moisture retention and buffering capacity against weather extremes.

INM Practices in Major Fruit Crops

Mango

- ✓ Application of FYM (20-25 kg tree⁻¹), NPK (500:250:250 g tree⁻¹) and biofertilizers like Azospirillum and phosphate solubilizing bacteria.
- ✓ Micronutrient sprays (e.g., boron and zinc) during flowering and fruit development.

Banana

- ✓ Use of vermicompost (10-15 kg plant⁻¹), neem cake (1-2 kg), and integrated application of NPK along with Trichoderma.
- ✓ Drip fertigation is effective for efficient nutrient delivery.

Citrus (e.g., Sweet Orange, Lime)

- ✓ Balanced NPK along with organic manure and zinc, boron foliar sprays.
- ✓ Mycorrhizal fungi are especially useful in improving phosphorus uptake.

Pomegranate

- ✓ FYM (10-15 kg plant⁻¹), NPK (600:250:250 g plant⁻¹) and regular use of biofertilizers.

- ✓ Boron application helps in improving flowering and fruit setting.

Grapes

- ✓ Fertilization based on leaf tissue analysis.

Emphasis on organic amendments and micro-nutrient sprays for uniform berry development.

Steps for Implementing INM in Fruit Orchards

Soil and Leaf Testing

- ✓ Identify existing nutrient levels and deficiencies.
- ✓ Helps formulate crop-specific nutrient schedules.

Nutrient Budgeting

- ✓ Calculate nutrient needs based on yield targets and crop type.
- ✓ Match with available nutrient sources (organic + inorganic).

Application Scheduling

- ✓ Apply nutrients at critical growth stages (e.g., flowering, fruit set, fruit enlargement).
- ✓ Use split doses to avoid losses and enhance uptake.

Use of Biofertilizers

- ✓ Inoculate seedlings or apply at planting and key stages.
- ✓ Combine with compost for better colonization.

Monitoring and Record-Keeping

- ✓ Observe crop response, pest/disease incidence and adjust practices accordingly.

Challenges in Adopting INM

- ✓ Lack of awareness among farmers about biofertilizers and organic inputs.
- ✓ Availability and quality of organic manures and biofertilizers.

- ✓ Labor-intensive nature of composting and organic material management.

- ✓ Difficulty in standardizing doses due to variation in nutrient content in organic sources.

These challenges can be overcome through extension services, training programs, government subsidies, and technology transfer initiatives.

Government and Institutional Support

Many governments and agricultural institutions now promote INM through:

- ✓ Subsidies for organic inputs
- ✓ Soil health card schemes
- ✓ Training and demonstration programs
- ✓ Promotion of on-farm composting and vermiculture units

Research institutions like ICAR (Indian Council of Agricultural Research), FAO, and others are developing crop-specific INM models tailored to local agro-climatic conditions.

Conclusion

Integrated Nutrient Management is not merely a practice but a philosophy of sustainable fruit production. It addresses the twin challenges of enhancing productivity and preserving soil and environmental health. With the global emphasis on sustainable agriculture, INM offers a promising pathway for farmers to cultivate high-quality fruits, reduce input costs, and protect the ecological balance. The success of INM depends on proper planning, farmer education, and support systems that encourage the integrated use of all available nutrient sources in a balanced and efficient manner.

Exotic Fruit Production Opportunities in India: Unlocking New Horizons in Horticulture

Sumit Bura, Amit Jasrotia and Arti Sharma

Introduction

India is one of the world's largest producers of fruits, boasting a diverse climate that supports the cultivation of a wide range of tropical, subtropical, and temperate fruits. While traditional fruits like mango, banana, guava, and papaya dominate the Indian horticultural landscape, a growing segment of health-conscious and globally exposed consumers is creating strong demand for exotic fruits. With increasing urbanization, changing food habits, and rising disposable incomes, exotic fruits such as dragon fruit, kiwi, avocado, passion fruit, rambutan, and mangosteen are gaining popularity in India. This shift opens up significant opportunities for Indian farmers, entrepreneurs, and agribusinesses to venture into exotic fruit cultivation. It also offers prospects for import substitution, value-added products, and export-oriented horticulture.

What Are Exotic Fruits?

Exotic fruits are those that are not native to a country or are grown in limited quantities outside their traditional regions. In India, fruits like kiwi, avocado, dragon fruit, rambutan, longan, passion fruit, and durian are considered exotic because they are either recently introduced or cultivated on a limited scale. These fruits are often:

- ✓ Rich in nutrients, antioxidants, and health benefits.
- ✓ Aesthetic and appealing for premium markets.
- ✓ Sold at higher prices compared to traditional fruits

Why Exotic Fruits Are Gaining Popularity in India

Health and Wellness Trend: Exotic fruits are often marketed as “superfoods” due to their high antioxidant content, dietary fiber, and essential nutrients. Fruits like avocado (healthy fats), kiwi (vitamin C), and dragon fruit (fiber and antioxidants) are becoming staples in health-conscious diets.

Exposure to Global Cuisine: Increased travel, digital media, and international food chains have introduced Indians to global cuisines that include exotic fruits in salads, smoothies, desserts, and breakfast bowls.

Rising Demand in Tier-I and Tier-II Cities:

Supermarkets, e-commerce platforms, and organic food stores are stocking a wider range of imported and locally grown exotic fruits, catering to an expanding affluent customer base.

Higher Profit Margins: Compared to traditional fruit crops, exotic fruits command higher prices, offering better returns per unit of land if managed

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correctly.

Climatic and Agroecological Suitability in India

India's diverse agro-climatic zones from the tropical south to the temperate north offer ideal conditions for cultivating many exotic fruits. For example:

North-East India: Suitable for passion fruit, kiwi, and citrus-like fruits.

South India (Tamil Nadu, Kerala): Ideal for avocado, rambutan, mangosteen.

Western India (Maharashtra and Gujarat): Increasing area under dragon fruit.

Hilly regions (Himachal Pradesh, Uttarakhand): Suited for kiwi, olive, and temperate exotic fruits.

Many of these fruits also require less pesticide use, making them suitable for organic or natural farming systems.

Promising Exotic Fruits for Cultivation in India

Dragon Fruit (Pitaya)

Origin: Central America

Suitability: Grows well in arid, semi-arid regions with minimal water.

States: Maharashtra, Gujarat, Andhra Pradesh, Karnataka

Highlights

- ✓ High demand in domestic and export markets.
- ✓ Income potential of ₹6-10 lakhs acre⁻¹ year⁻¹.
- ✓ Fruits within 12-15 months of planting.

Avocado (Butter Fruit)

Origin: Central America

Suitability: Requires humid, subtropical conditions

States: Tamil Nadu, Karnataka, Kerala, Maharashtra

Highlights

- ✓ Rich in healthy fats and fiber
- ✓ Strong demand in metro cities
- ✓ Slow to fruit (3-4 years), but highly profitable

Kiwi

Origin: China/New Zealand

Suitability: Temperate and sub-temperate regions

States: Arunachal Pradesh, Himachal Pradesh, Sikkim

Highlights

- ✓ Replaces imports (India imports over 4,000 tonnes annually)
- ✓ Requires trellis support, well-drained soil
- ✓ High export potential to Gulf and Southeast Asia

Passion Fruit

Origin: South America

Suitability: Grows well in warm, humid regions

States: Nagaland, Manipur, Kerala, Tamil Nadu

Highlights

- ✓ Used in juices, desserts and value-added products
- ✓ Quick returns (fruiting within 1 year)
- ✓ Compatible with organic farming

Rambutan and Mangosteen

Origin: Southeast Asia

Suitability: Tropical humid regions

States: Kerala, Tamil Nadu, Andaman & Nicobar Islands

Highlights

- ✓ Niche markets with high selling prices
- ✓ Suitable for intercropping with coconut or arecanut

Market and Economic Potential

India's import bill for exotic fruits like kiwi, avocado, and dragon fruit has surged in the past decade. This indicates strong unmet domestic demand. Cultivating these fruits domestically can:

- ✓ Reduce dependency on imports
- ✓ Offer lucrative opportunities to small and marginal farmers
- ✓ Enhance rural employment in orchard management, post-harvest handling and processing
- ✓ Open up avenues for agri-tourism and boutique orchards

According to APEDA and National Horticulture Board (NHB) data:

- ✓ Dragon fruit can yield up to 10-15 tonnes acre⁻¹ by the third year.
- ✓ Kiwi commands prices of ₹200-300 kg⁻¹ in urban markets.
- ✓ Avocado sells for ₹300-600 kg⁻¹ in Tier-I cities.

These figures suggest a strong economic incentive for diversification into exotic fruit cultivation.

Post-Harvest and Value Addition Opportunities

Exotic fruits are highly perishable and require careful post-harvest management. Opportunities include:

- ✓ Cold storage and ripening chambers
- ✓ Grading and packaging units
- ✓ Juice and pulp extraction units
- ✓ Freeze-drying and dehydration
- ✓ Export packaging and airfreight logistics

Value-added products like avocado oil, dragon fruit jam, kiwi juice, and passion fruit concent

-rate have high market value and shelf stability, boosting farmer profits and reducing post-harvest losses.

Government Support and Initiatives

Recognizing the potential, the Indian government and various state horticulture departments are promoting exotic fruit cultivation through:

- ✓ Subsidies under MIDH (Mission for Integrated Development of Horticulture)
- ✓ Support for protected cultivation, trellising, and drip irrigation
- ✓ Research and development through ICAR institutes like IIHR (Bangalore), CHES (Bhutanagar) and CAU (Imphal)
- ✓ Export facilitation through APEDA for value-added exotic products

States like Gujarat, Maharashtra, and Arunachal Pradesh have announced special schemes to encourage dragon fruit and kiwi cultivation with input subsidies and marketing support.

Challenges in Exotic Fruit Cultivation

While the opportunity is substantial, several challenges exist:

Lack of Awareness and Expertise: Many farmers are unfamiliar with cultivation techniques, pests, and nutrient needs of exotic fruits.

High Initial Investment: Cost of planting material, support structures, irrigation, and post-harvest handling is significant.

Limited Quality Planting Material: Shortage of certified nurseries and elite planting stock for many exotic species.

Market Access: Farmers need access to premium markets, logistics, and branding strategies to realize full value.

Pest and Disease Surveillance: Exotic crops may attract unfamiliar pests; ongoing R&D and monitoring are essential.

Recommendations for Success

Cluster-based approach: Cultivate exotic fruits in identified zones with common facilities for storage, marketing, and processing.

Farmer training and demonstration: Regular workshops on orchard management, pruning, and nutrition.

Contract farming and FPO models: Aggregation of produce for better bargaining power and access to institutional buyers.

Private sector involvement: Nurseries, exporters, and agri-tech startups can partner with farmers for end-to-end support.

Digital marketing and branding: Leverage online platforms and direct-to-consumer channels for premium pricing.

Conclusion

The cultivation of exotic fruits in India offers a golden opportunity to diversify agriculture, boost farmer incomes and meet growing consumer demand for healthful, premium produce. With the right blend of government support, private investment, and farmer engagement, India can emerge as a major producer and exporter of select exotic fruits in the years ahead. As the world moves towards healthier lifestyles and sustainable food systems, exotic fruit

cultivation could be one of the pillars of India's horticultural transformation.

Architectural Engineering in Fruit Crops: Designing for Productivity and Sustainability

Sumit Bura, Amit Jasrotia and Arti Sharma

Introduction

Architectural engineering in horticulture specifically in fruit crops refers to the science and practice of shaping the structural design, spatial arrangement, and growth pattern of fruit plants to maximize productivity, improve fruit quality, reduce labor input and enhance overall orchard sustainability. While commonly associated with buildings and infrastructure, architectural principles apply significantly to agriculture, especially in orchard planning and canopy management. In fruit cultivation, architectural engineering involves strategic decisions about plant spacing, training systems, pruning techniques, canopy design, rootstock selection and mechanization compatibility. The aim is to create a plant structure that optimally utilizes sunlight, nutrients, space and water while facilitating ease of management practices such as pest control, harvesting, and irrigation. This article explores how architectural engineering is revolutionizing fruit farming in India and globally, with a focus on modern orchard designs, high-density planting, and the integration of mechanization and precision horticulture.

Importance of Plant Architecture in Fruit Crops

The architecture of a fruit plant determines

how well it can intercept light, bear fruit efficiently, resist diseases, and allow for human intervention such as pruning, spraying, or harvesting. A well-engineered orchard structure can lead to:

- ✓ Enhanced photosynthetic efficiency due to better light penetration.
- ✓ Increased fruit yield and quality.
- ✓ Lower labor and input costs through easier management.
- ✓ Improved air circulation, reducing pest and disease incidence.
- ✓ Efficient mechanization and automation potential.
- ✓ Better space utilization per unit area

With limited land availability and growing demand for fruits, architectural optimization has become essential for achieving higher productivity per hectare.

Key Elements of Architectural Engineering in Fruit Crops

Planting Geometry and Spacing

- ✓ Traditional planting often involves wide spacing (e.g., mango at 10x10 meters), leading to underutilized space, especially in early years.
- ✓ Architectural engineering promotes optimized layouts such as square, rectangular, quincunx, or

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triangular systems based on the crop, topography and climate.

- ✓ Example: High-Density Mango Orchards use 3x2 or 4x3 meter spacing, increasing plant population from 100 to over 500 trees per hectare.

Training and Pruning Systems

Proper training (directing the growth of plant structure) and pruning (removing specific parts of the plant) help control plant shape, regulate crop load, and enhance light interception. Common training systems include:

- ✓ Open Center (used in peach, plum)
- ✓ Central Leader (apple, pear)
- ✓ Modified Central Leader (mango, sapota)
- ✓ Tatura Trellis (used in apple, kiwi, guava)
- ✓ Espalier and Vertical Wall Systems (in modern orchards for mechanized pruning/harvesting)

Well-trained trees ensure better canopy management, reduce alternate bearing, and improve the uniformity of fruit development.

Canopy Architecture and Light Interception

The canopy is the part of the plant above ground, including branches and leaves. Architectural engineering focuses on:

- ✓ Maintaining optimal leaf area index (LAI) for maximum photosynthesis.
- ✓ Ensuring even light distribution within the canopy.
- ✓ Avoiding excessive shading and encouraging fruiting at desirable heights.

By modifying canopy shape (conical, vase-

shaped, flat, etc.), farmers can maximize light use efficiency, reduce disease pressure, and encourage uniform ripening.

High-Density Planting (HDP): A Breakthrough in Orchard Design

High-Density Planting (HDP) is a prime example of architectural engineering. It involves planting more trees per unit area without compromising tree health or fruit quality, made possible through the use of dwarf or semi-dwarf rootstocks, training systems and growth regulators.

Benefits of HDP

- ✓ Increased productivity (up to 2-3 times more per hectare)
- ✓ Earlier returns on investment (fruiting within 2–3 years).
- ✓ Better management and ease of operations
- ✓ Improved fruit quality due to better canopy control

Fruit Crops with Successful HDP Models

Apple: Super spindle system with 2,000-3,000 trees ha⁻¹ using M9 rootstock.

Guava: Meadow orchard system with 2x1 m spacing and regular pruning.

Mango: Ultra-high-density planting with 3x2 m spacing and dwarf cultivars.

Banana: 1.2x1.5 m spacing with drip irrigation and fertigation.

Papaya: 1.5x1.5 m spacing to reduce competition and increase airflow.

HDP is supported by institutions like ICAR-CISH (for mango), ICAR-IIHR (for guava and

papaya) and ICAR-CITH (for apple).

Use of Trellising and Support Structures

In vining or sprawling fruit crops such as grape, kiwi, passion fruit, and dragon fruit, trellising plays a critical architectural role.

Common trellis systems include

- ✓ Bower system (grapes)
- ✓ Tatura trellis (apple, pear)
- ✓ Vertical/horizontal trellis (kiwi, passion fruit)
- ✓ Concrete pole and ring structure (dragon fruit)

Trellis-based designs

- ✓ Improve plant exposure to sunlight
- ✓ Ease harvesting and pruning
- ✓ Enhance air movement and disease management
- ✓ Improve space use and yield per unit area

Architectural Engineering in Protected Cultivation

The architecture of fruit crops under greenhouses, shade nets or polyhouses needs additional precision in spacing, trellising, and vertical growth control. This is especially useful for:

Strawberry: Vertical stacks or table-top growing systems.

Papaya: Dwarf varieties grown under net houses to protect from virus.

Fig, raspberry, blueberry: Controlled structures for export-quality produce.

Protected architectural systems are integrated with drip irrigation, sensor-based climate control, and vertical farming models, making fruit cultivation feasible even in non-traditional regions.

Integration with Mechanization and Robotics

Smart orchard architecture also considers future integration with mechanization, especially for large-scale or export-oriented operations. Benefits include:

- ✓ Compatibility with mechanical harvesters and sprayers
- ✓ Use of drones for pesticide application and monitoring
- ✓ Robotic arms for fruit picking in structured canopies (apples, berries)
- ✓ Easier deployment of IoT devices and AI for precision horticulture

Orchard layouts and canopy shapes are now being designed with automation readiness, improving operational efficiency.

Rootstock Selection and Growth Habit Control

Rootstocks influence tree vigor, canopy size, disease resistance, and yield. Choosing the right rootstock is a critical architectural decision.

Examples

M9 in apple: Dwarfing, early bearing, suited for HDP

Vellaikolumban in mango: Used for dwarfing Alphonso variety

PSB-G6 in guava: Reduces canopy size and improves fruit quality

Growth regulators such as Paclobutrazol (mango) or ethephon (guava) are also used to control vegetative growth and enhance reproductive architecture.

Challenges in Implementing Architectural Engineering

- ✓ Lack of technical knowledge among farmers about training systems and pruning schedules
- ✓ High initial investment in support structures and planting materials
- ✓ Skilled labor required for canopy management and precision pruning
- ✓ Need for region-specific models considering local climate and soil
- ✓ Integration with market demand to ensure economic viability

Addressing these challenges requires capacity building, extension services, and collaboration between researchers, nurseries, and growers.

The Way Forward: Sustainable Orchard Architecture

Future orchard designs will likely combine biological efficiency with technological integration, including:

- ✓ AI-driven layout planning
- ✓ 3D modeling of orchard structures
- ✓ Dynamic canopy sensors to monitor leaf area and fruit load
- ✓ Agroforestry-inspired multi-layered systems for environmental sustainability

Architectural engineering in fruit crops is poised to drive the next wave of transformation in horticulture, aligning productivity with environmental stewardship and economic resilience.

Conclusion

Architectural engineering in fruit crops is not just about aesthetics it is a critical discipline that influences the success, sustainability and profitability

of modern orchards. From high-density planting to trellis design and canopy management, every structural decision impacts the plant's ability to grow, flower, and fruit optimally. In an era where climate variability, land scarcity, and food security are pressing issues, scientifically designed orchards offer a powerful solution. By adopting principles of architectural engineering, Indian horticulture can move toward a future that is more productive, resource-efficient, and climate-resilient, ensuring both farmer prosperity and consumer satisfaction.

Crop Regulation in Fruit Crops: Strategies for Sustainable Yield and Quality

Sumit Bura, Amit Jasrotia and Arti Sharma

Introduction

Crop regulation in fruit crops is a critical aspect of horticultural management aimed at controlling the timing, intensity, and uniformity of flowering and fruiting to ensure optimum yield, quality, and marketability. Unlike annual crops, fruit crops are perennial and tend to exhibit irregular bearing patterns such as biennial (alternate) bearing or erratic flowering leading to inconsistent yields and economic losses. The goal of crop regulation is to synchronize fruit production with market demand, optimize resource use, and improve the physiological balance of the plant. Through a combination of cultural, mechanical, hormonal, and chemical techniques, crop regulation ensures that fruit plants produce high-quality fruits consistently over the years.

Need for Crop Regulation

Alternate Bearing Management: Many fruit trees (e.g., mango, litchi, citrus) show alternate or biennial bearing, producing a heavy crop one year and little to none the next. Crop regulation helps stabilize yields annually.

Market-Oriented Production: By controlling flowering and fruiting times, growers can align harvests with periods of high market demand and

better prices.

Improved Fruit Quality: Crop regulation reduces fruit overcrowding and competition, improving size, sweetness, color, and shelf life.

Plant Health and Longevity: Preventing overbearing in one season reduces physiological stress, helping plants remain healthy and productive for longer.

Resource Optimization: Controlled fruiting allows better use of water, nutrients, and labor resources, enhancing input efficiency.

Major Fruit Crops Needing Crop Regulation

Mango: Prone to biennial bearing

Guava: Multiple flowering seasons; needs off-season regulation

Pomegranate: Requires season-specific flowering for export markets

Citrus: Irregular flowering in tropical conditions

Sapota, Ber and Papaya: benefit from managed flowering and fruit set.

Methods of Crop Regulation

Crop regulation involves both natural and artificial methods to manage flowering and fruiting. These include:

Cultural Methods

Bahār Treatment (Seasonal Flowering Regula-

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on): Used in crops like pomegranate and citrus to induce flowering in a specific season (Mrig Bahār, Ambe Bahār, Hasth Bahār) by manipulating irrigation and pruning.

- ✓ Withholding irrigation post-harvest causes leaf fall and dormancy.
- ✓ Resuming irrigation and pruning triggers synchronized flowering.
- ✓ Common in Maharashtra, Gujarat and Karnataka.

Pruning

- ✓ Removes old, unproductive wood and stimulates new shoots.
- ✓ Used in guava, ber, grape, pomegranate to induce flowering.
- ✓ In guava, pruning is often timed to favor the winter crop, which yields better quality fruits.

Deblossoming

- ✓ In alternate-bearing species like mango, excessive fruit set is thinned to avoid stress and ensure flowering in the following year.
- ✓ Manual removal of panicles or young fruits helps achieve balance.

Nutritional Regulation

- ✓ Balanced fertilization, particularly with potassium and phosphorus, helps support flowering and fruit set.
- ✓ Avoiding excess nitrogen prevents excessive vegetative growth at the expense of flowering.
- ✓ Micronutrient sprays (e.g., boron, zinc) during pre-flowering stages improve floral development and fruit set.

Hormonal and Chemical Regulation

Plant growth regulators (PGRs) play a significant role in crop regulation:

Ethephon (Ethrel)

- ✓ Used in mango and guava to cause flower thinning or shift flowering to desired seasons.
- ✓ Application in “on-year” in mango suppresses flowering, promoting return bloom in the following year.

Naphthalene Acetic Acid (NAA)

- ✓ Applied to thin excess fruitlets in apple, guava, and citrus.
- ✓ Helps in uniform fruit size and quality.

Paclobutrazol (PBZ)

- ✓ A popular chemical used in mango to induce flowering during the off-year.
- ✓ Inhibits gibberellin synthesis, promoting reproductive growth.

Gibberellic Acid (GA₃)

- ✓ Used in grape and citrus to manipulate flowering and fruit development.
- ✓ GA₃ sprays delay flowering or enhance fruit elongation, depending on crop and timing.

Mechanical and Physical Methods

- ✓ Hand thinning of flowers or young fruits in crops like mango, apple, and guava.
- ✓ Girdling or notching in grape and citrus: disrupts phloem flow, enhancing flowering or fruit retention.
- ✓ Water stress or controlled irrigation to simulate dormancy or rest period, especially in subtropical crops.

Crop-Specific Regulation Practices

Mango (*Mangifera indica*)

- ✓ Alternate bearing is a major issue.
- ✓ Deblossoming in “on” year combined with Paclobutrazol (PBZ) soil application in “off” year.
- ✓ Timed pruning in some cultivars improves return bloom.

Guava (*Psidium guajava*)

- ✓ Flowers 2-3 times a year (rainy, winter, spring seasons).
- ✓ Winter crop is preferred for better quality.
- ✓ Bahār pruning in June or September, withholding water, and NAA spray helps regulate flowering.

Pomegranate (*Punica granatum*)

- ✓ Three flowering seasons: Ambe, Mrig, and Hasth Bahār.
- ✓ Regulation through bahār treatment: root exposure, water withholding, pruning and fertilization.
- ✓ Choice of bahār depends on market demand and climate.

Citrus (*Citrus spp.*)

- ✓ Flowering is irregular in tropical climates.
- ✓ Water stress, pruning, and hormone sprays (GA₃, 2,4-D) help manage flowering.
- ✓ Flowering in citrus is often triggered by sudden changes in temperature and water availability.

Challenges in Crop Regulation

Labor-intensive: Manual pruning or thinning is costly and time-consuming.

Climate sensitivity: Success depends on temperature, rainfall, and humidity.

Chemical misuse: Overuse of PGRs like PBZ can harm soil health and plant vigor.

Lack of awareness: Many farmers lack training in crop regulation techniques.

Market unpredictability: Difficulty in aligning regulated crops with fluctuating market demand.

Best Practices and Recommendations

- ✓ Plan crop regulation based on local climate and market cycles.
- ✓ Integrate pruning, irrigation, and nutrient management with growth regulator application.
- ✓ Monitor tree physiology (flowering behavior, leaf age) for timely interventions.
- ✓ Use recommended doses of PGRs and follow safety protocols.
- ✓ Promote training and awareness among farmers through Krishi Vigyan Kendras (KVKs) and horticulture departments.
- ✓ Encourage record-keeping to track yield responses over the years and refine techniques.

Conclusion

Crop regulation is an essential horticultural practice that enables fruit growers to stabilize yields, enhance fruit quality, and ensure economic sustainability. By combining scientific techniques with traditional knowledge, farmers can better manage perennial fruit crops and meet the evolving demands of the market. Whether it's controlling flowering in mango or aligning guava harvests to high-demand seasons, crop regulation is a strategic tool that plays a central role in modern fruit farming. As Indian horticulture moves towards precision,

sustainability, and profitability, adopting well-timed and crop-specific regulation practices will be key to unlocking the true potential of fruit crops across diverse agro-climatic regions.



CO₂ Concentration Mechanisms in C₄ Plants

K. Manoj Kumar, S. Nadaradjan and M. Vaishnavi

C₄ cycle or Hatch and Slack pathway

- ✓ It is the alternate pathway of C₃ cycle to fix CO₂.
- ✓ In this cycle, the first formed stable compound is a 4 carbon compound viz., oxaloacetic acid. Hence it is called C₄ cycle.
- ✓ The path way is also called as Hatch and Slack as they worked out the pathway in 1966 and it is also known as C₄ dicarboxylic acid pathway.

Examples: Grasses, sugar cane, maize, sorghum and amaranthus.

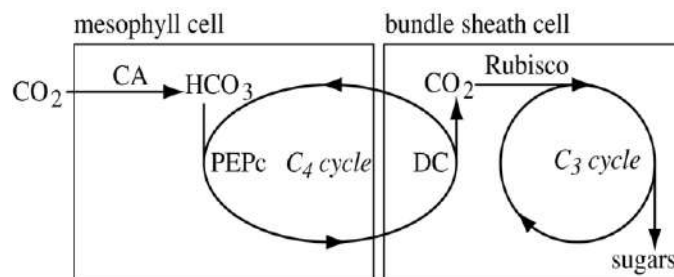
Kranz Anatomy

- ✓ The C₄ plants show a different type of leaf anatomy. The chloroplasts are dimorphic in nature.
- ✓ In the leaves of these plants, the vascular bundles are surrounded by bundle sheath of larger parenchymatous cells.
- ✓ These bundle sheath cells have chloroplasts. These chloroplasts of bundle sheath are larger, lack grana and contain starch grains.
- ✓ The chloroplasts in mesophyll cells are smaller and always contain grana.
- ✓ This peculiar anatomy of leaves of C₄ plants is called Kranz anatomy.
- ✓ Kranz in German means wreath and hence it is called Kranz anatomy.

CO₂-Concentrating Mechanisms: The C₄ Carbon Cycle

There are differences in leaf anatomy between plants that have a C₄ carbon cycle (called C₄ plants) and those that photosynthesize solely via the Calvin photosynthetic cycle (C₃ plants). Across section of a typical C₃ leaf reveals one major cell type that has chloroplasts, the mesophyll. In contrast, a typical C₄ leaf has two distinct chloroplast-containing cell types: mesophyll and bundle sheath (or Kranz, German for “wreath”) cells. There is considerable anatomic variation in the arrangement of the bundle sheath cells with respect to the mesophyll and vascular tissue.

In all cases, however, operation of the C₄ cycle requires the cooperative effort of both cell types. No mesophyll cell of a C₄ plant is more than two or three cells away from the nearest bundle sheath cell. In addition, an extensive network of plasmodesmata connects mesophyll and bundle sheath cells, thus providing a pathway for the flow of metabolites between the cell types.



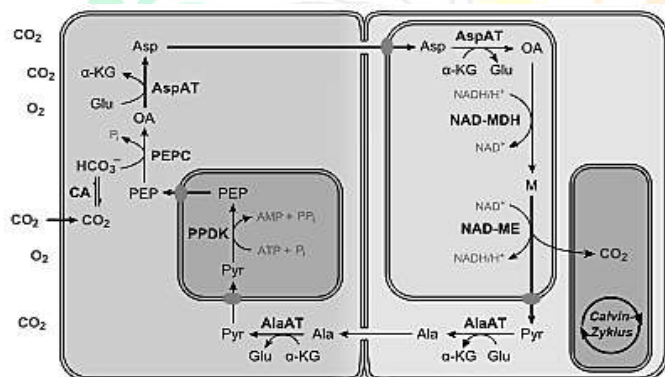
Malate and Aspartate are Carboxylation Products of the C₄ Cycle

Early classification of C₄ acids was first observed

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in 14 CO₂ labeling studies of sugarcane by H. P. Kortschack and colleagues and of maize by Y. Karpilov and coworkers. When leaves were exposed for a few seconds to 14 CO₂ in the light, 70 to 80% of the label was found in the C₄ acids malate and aspartate a pattern very different from the one observed in leaves that photosynthesize solely via the Calvin cycle. In pursuing these initial observations, M. D. Hatch and C. R. Slack elucidated what is now known as the C₄ photosynthetic carbon cycle (C₄ cycle). They established that the C₄ acids malate and aspartate are the first stable, detectable intermediates of photosynthesis in leaves of sugarcane and that carbon atom 4 of malate subsequently becomes carbon atom 1 of 3-phosphoglycerate.



The primary carboxylation in these leaves is catalyzed not by rubisco, but by PEP (phosphoenolpyruvate) carboxylase (Chollet *et al.*, 1996). The manner in which carbon is transferred from carbon atom 4 of malate to carbon atom 1 of 3-phosphoglycerate became clear when the involvement of mesophyll and bundle sheath cells was elucidated. The participating enzymes occur in one of the two cell types: PEP carboxylase and pyruvate orthophosphate dikinase are restricted to mesophyll cells; the

decarboxylases and the enzymes of the complete Calvin cycle are confined to the bundle sheath cells. With this knowledge, Hatch and Slack were able to formulate the basic model of the cycle.

The C₄ Cycle Concentrates CO₂ in Bundle Sheath Cells

The basic C₄ cycle consists of four stages:

- ✓ Fixation of CO₂ by the carboxylation of phosphoenolpyruvate in the mesophyll cells to form a C₄ acid (malate and/or aspartate).
- ✓ Transport of the C₄ acids to the bundle sheath cells
- ✓ Decarboxylation of the C₄ acids within the bundle sheath cells and generation of CO₂, which is then reduced to carbohydrate via the Calvin cycle
- ✓ Transport of the C₃ acid (pyruvate or alanine) that is formed by the decarboxylation step back to the mesophyll cell and regeneration of the CO₂ acceptor phosphoenolpyruvate.

One interesting feature of the cycle is that regeneration of the primary acceptor phosphoenolpyruvate consumes two “high-energy” phosphate bonds: one in the reaction catalyzed by pyruvate–orthophosphate dikinase, and another in the conversion of PP_i to 2P_i catalyzed by pyrophosphatase. Shuttling of metabolites between mesophyll and bundle sheath cells is driven by diffusion gradients along numerous plasmodesmata, and transport within the cells is regulated by concentration gradients and the operation of specialized translocators at the chloroplast envelope.

The cycle thus effectively shuttles CO_2 from the atmosphere into the bundle sheath cells. This transport process generates a much higher concentration of CO_2 in the bundle sheath cells than would occur in equilibrium with the external atmosphere. This elevated concentration of CO_2 at the carboxylation site of rubisco results in suppression of the oxygenation of ribulose-1,5-bisphosphate and hence of photorespiration. Discovered in the tropical grasses, sugarcane, and maize, the C_4 cycle is now known to occur in 16 families of both monocotyledons and dicotyledons, and it is particularly prominent in Gramineae (corn, millet, sorghum, sugarcane), Chenopodiaceae (Atriplex) and Cyperaceae (sedges).

About 1% of all known species have C_4 metabolism (Edwards and Walker, 1983). There are three variations of the basic C_4 pathway that occur in different species. The variations differ principally in the C_4 acid (malate or aspartate) transported into the bundle sheath cells and in the manner of decarboxylation.

The Concentration of CO_2 in Bundle Sheath Cells Has an Energy Cost

The net effect of the C_4 cycle is to convert a dilute solution of CO_2 in the mesophyll cells into a concentrated CO_2 solution in cells of the bundle sheath. Studies of a PEP carboxylase deficient mutant of *Amaranthus edulis* clearly showed that the lack of an effective mechanism for concentrating CO_2 in the bundle sheath markedly enhances photorespiration in a C_4 plant (Dever *et al.*, 1996).

Thermodynamics tells us that work must be done to establish and maintain the CO_2 concentration gradient in the bundle sheath. This principle also applies to the operation of the C_4 cycle. From a summation of the reactions involved, we can calculate the energy cost to the plant. The calculation shows that the CO_2 -concentrating process consumes two ATP equivalents (2“high-energy” bonds) per CO_2 molecule transported. Thus the total energy requirement for fixing CO_2 by the combined C_4 and Calvin cycles is five ATP plus two NADPH per CO_2 fixed. Because of this higher energy demand, C_4 plants photosynthesizing under non photorespiratory conditions (high CO_2 and low O_2) require more quanta of light per CO_2 than C_3 leaves do. In normal air, the quantum requirement of C_3 plants changes with factors that affect the balance between photosynthesis and photorespiration, such as temperature. By contrast, owing to the mechanisms built in to avoid photorespiration, the quantum requirement of C_4 plants remains relatively constant under different environmental conditions.

Biochar Application for the Remediation of Problematic Soils

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Abstract

In the domain of agriculture, soil health plays a crucial role that influence crop productivity. Soil degradation is a significant global environmental issue that threatens agricultural productivity, biodiversity and ecosystem, it refers to the decline in soil quality due to natural processes and human activities. Problematic soils play major role in soil degradation, that have physical, chemical and biological characteristics that hinder plant growth, reduce agricultural productivity and disrupt ecological processes. These soils, which are widespread across various regions of the country, require effective management strategies to restore their fertility and enhance agricultural output. One of the promising solutions is the use of organic amendments like farmyard manure, poultry manure, compost, pressmud and biochar. Research has shown that these amendments improve plant growth by enhancing the physical, chemical and biological properties of these challenging soils. Biochar has been found to significantly improve the condition of soils by improving their structure, in addition to potentially neutralizing soil pH and increasing nutrients availability. Low-temperature biochar is considered more suitable for agricultural use due to its higher cation exchange capacity and greater quantity of functional chemical groups.

Introduction

Realizing mounting demand for adequate and highly nutritious food for the rising human population, there is need to increase both quantity and quality of crop production. One way for improving the crop productivity is through modifying the soil nutrient supply and by the better management of different problematic soils. Problematic soils such as those suffering from salinity, acidity, heavy metal contamination, nutrient deficiency, or poor structure

are increasingly common due to unsustainable land management practices, industrial activities, and climate change. These soils generally have low fertility, poor water retention, and reduced microbial activity, which can severely limit plant growth and agricultural potential (Dahlawi *et al.*, 2018). Biochar is a stable, carbon-rich material produced through the pyrolysis of organic biomass under limited oxygen conditions, has emerged as a promising soil amendment for the remediation of such problematic soils.

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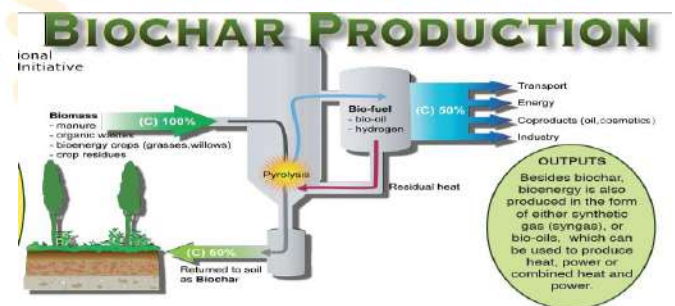
Its unique physicochemical properties, including high surface area, porosity, and cation exchange capacity, allow it to improve soil structure, enhance nutrient retention, and immobilize contaminants. Biochar application supports the development of beneficial microbial communities, enhances soil organic matter and reduces greenhouse gas emissions, these effects make it a good option for restoring degraded soils in a sustainable and environmentally friendly manner (Chintala et al. 2013). However, the effectiveness of biochar largely depends on factors such as the type of feedstock used, pyrolysis conditions, application rates, and the specific characteristics of the soil.

Four main components of biochar

Biochar is composed of four main components, fixed carbon, volatile compounds, Moisture and ash each contributing uniquely to its function as a soil amendment. Carbon, primarily in the form of stable aromatic structures formed during pyrolysis, is the dominant component and plays a crucial role. Ash, which consists of inorganic minerals such as potassium, calcium, magnesium, and phosphorus, contributes to the nutrient value of biochar and helps to neutralize soil acidity, making it especially beneficial for acidic or nutrient-depleted soils. Volatile matter includes partially decomposed organic compounds that were not fully carbonized during pyrolysis; these compounds can serve as a short-term energy source for soil microbes and influence the biochar's chemical reactivity (Lehmann and Joseph, 2015).

Component	Quantity (%)
Fixed carbon	50-90
Volatile compounds	0-40
Moisture	1-15
Mineral content (ash)	0.5-55

Pyrolysis: Pyrolysis is a thermochemical decomposition process of organic materials conducted at high temperatures (300°C and 900°C) in the absence or near-absence of oxygen. Pyrolysis can be categorized into slow, fast, and intermediate pyrolysis, depending on the heating rate and residence time, each influencing the proportion of products formed. It is widely used for converting biomass into renewable fuels, chemicals and carbon-rich residues. In environmental and industrial contexts, pyrolysis offers sustainable solutions such as waste-to-energy conversion, biochar production for soil enhancement and recovery of valuable compounds from waste streams (Makavana et al., 2020).



Various pyrolysis processes and their products

Mode	Condition	Liquid (bio-oil)	Solid (bio-char)	Gas (syngas)
Fast pyrolysis	Moderate temperature (425–600 °C)	75 %	12 %	13 %
Intermediate pyrolysis	Low to moderate temperature (450–550 °C)	50 %	25 %	25 %
Slow pyrolysis	Low to moderate temperature (300–550 °C)	30 %	35 %	35 %
Gasification	High temperature (> 800 °C)	5 %	10 %	85 %
Torrefaction	(450–550 °C)	20 %	75 %	5 %

Biochar amendment improves problem soil properties

Due to their organic nature (60-80% C) and

highly active surface area and functionality, biochar have been used for improving soil quality. The rich black soil known as “terra preta” created by Amazonian civilizations thousands of years ago has proven the value of biochar. Their amendment improves not only physical and chemical properties but also biological properties of soils, particularly the problem soils.

Physical properties improvement: Biochar amendment reduces both bulk density (3-33%) and particle density of soils, increased soil porosity by 8.4% due in part to the porosity of biochar (70-90%). The decrease in bulk density and increase in soil porosity can improve the movement of water, heat, and gases in soils. Biochar can alter saturated hydraulic conductivity and reduce saturated water flow in coarse-textured soils and increase it in fine-textured soils. Biochar amendment reduces soil tensile strength and increases water retention (Mahmoud *et al.*, 2017).

Chemical properties improvement: Biochar application has been shown to significantly improve chemical properties of problem soils. Mineral elements, such as Ca, K, Mg, Na and Si in feedstocks form carbonates or oxides during the pyrolysis, which react with H^+ and Al in acid soils by reducing exchangeable acidity and increasing pH and cation exchange capacity. Application of acidic biochar to alkaline soils may improve soil pH, produced an acidic biochar with a pH of 5.8, application of the biochar to an eroded calcareous soil decreased soil pH between 0.2 and 0.4 units, while bioavailable P,

Mn, and Zn increased. As a remediation agent, biochar can effectively remove various heavy metals in contaminated soils. Biochar with large surface area, abundant pore volume, and rich functional groups are believed to have a large capacity for sorption of heavy metals. Biochar application can improve the fertility of problem soils. This is because biochar is considered as organic fertilizer containing organic C and plant nutrients, such as N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, and Si. Depending on the deficiency of nutrients in problem soils (Yu *et al.*, 2019).

Biological properties improvement: Biochar amendment can create favourable environment for microbes in problem soils. Biochar pores may act as a refuge site or micro-habitat for microbes. They use C, nutrients, gases, and water provided by biochar to grow and reproduce. Biochar application at a rate of 10 tonne ha^{-1} or higher lead to statistically significant increases in biological nitrogen fixation by red clove.



Conclusion

It is concluded that, biochar presents a multifaceted solution for the remediation of problematic soils. Its ability to enhance soil fertility, reduce contamination and support crop growth makes it a valuable addition to soil management practices. While its effectiveness is influenced by

materials used in the pyrolysis, application rates and timing. The appropriate use of biochar minimizes potential risks, ensuring long-term benefits for soil health and agricultural productivity.

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Integrated Pest Management Strategies for Fall Armyworm (*Spodoptera frugiperda* J. E. Smith)

Richa Gupta, Preeti Yadav, Anshuman Singh, Ayush Kumar and C. P. N. Gautam

Abstract

Fall armyworm (*Spodoptera frugiperda*) is a major pest affecting maize and other crops, causing serious economic losses. Integrated Pest Management (IPM) offers an eco-friendly and sustainable solution by combining various control methods. Cultural practices like crop rotation, intercropping, and timely planting help reduce pest buildup. Biological control involves using natural enemies such as parasitoids, predators and biopesticides like *Bacillus thuringiensis* and entomopathogenic fungi. Mechanical methods, including hand-picking and pheromone traps, aid in reducing pest populations. Chemical control is applied only when necessary, using selective insecticides to avoid resistance and protect beneficial organisms. Genetic approaches like pest-resistant varieties and *Bt* maize add further protection. Regular monitoring and community participation are essential for effective IPM implementation. This integrated approach reduces pesticide use, delays resistance, and ensures long-term control of fall armyworm, contributing to better yields and sustainable crop production. IPM is key to protecting food security and the environment.

Introduction

Maize, *Zea mays* L. is a member of the family: Poaceae also known as corn. It is one of the most flexible growing crops with greater adaptability to different agro-climatic conditions. Because of higher genetic yield potential among the cereals, this crop is globally popular as the “Queen of cereals” (Jeyaraman, 2017). Maize is an economically important cereal crop among the various cereals cultivated, which is generally cultivated in tropical as well as in sub-tropical parts of the world. Leafy stalks of maize produce ears, which contain grain and are called kernels or seeds. The kernels of maize are

most used as starch in cooking. The six major types of maize (corn) are dent corn, pod corn, flint corn, popcorn, flour corn and sweet corn (Smith, 2013). Although about 139 insect pests cause varying degree of damage to maize crop, but only about a dozen of these are quite serious and require control measures, *i.e.* maize stalk borer, pink stem borer, and shoofly are the insects of national importance, while the armyworm, jassid, thrips, pyrilla, grasshopper, white grub, cut worm, hairy caterpillar, termite, and the leaf miner are more serious pest of regional level.

Among them, fall armyworm renowned as invasive pests in India belongs to family Noctuidae.

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Fall armyworm invasion firstly reported in India on maize in Shivmogga district of Karnataka (Sharana-basappa *et al.*, 2019). Fall armyworm initially showed social behaviour and damage by scrapping the chlorophyll from one side of the leaves resulting in 'window pane' (formation of translucent patches) (Tiwari *et al.*, 2024). Fall army worm *S. frugiperda* mainly feed on leaf whorls, tassels, ears and cobs of maize, resulting in total yield occasionally (Sarmiento *et al.*, 2002). According to recent studies, fall armyworms can cause yield losses ranging from 8.3 to 20.6 million tonnes of maize per year in absence of management practices (Day *et al.*, 2017).



Integrated pest management strategies for fall armyworm

Integrated Pest Management (IPM) is a sustainable approach that combines biological, cultural, mechanical and chemical tools to manage pests like the fall armyworm (*Spodoptera frugiperda*).

Cultural Control

These methods modify the environment to make it less favorable for the pest:

Crop Rotation: Rotate maize with non-host crops like legumes (e.g., cowpea, soybean) to break the pest's life cycle.

Intercropping: Mix maize with crops that repel or distract fall armyworm, such as Desmodium or

Napier grass (as part of a push-pull system).

Timely Planting: Synchronize planting to avoid peak fall armyworm activity periods.

Field Sanitation: Remove crop residues and weeds that may harbor larvae or eggs.

Trap Crops: Plant crops that are more attractive to fall armyworm near maize fields to lure pests away.

Biological Control

Using natural enemies to keep populations in check:

Predators & Parasitoids

- ✓ *Telenomus remus* (egg parasitoid).
- ✓ *Trichogramma spp.* (egg parasitoid).
- ✓ *Cotesia marginiventris* (larval parasitoid).
- ✓ Predators like lady beetles, lacewings, and ants.

Entomopathogens

- ✓ *Bacillus thuringiensis* (Bt): Effective against early-instar larvae.
- ✓ Entomopathogenic fungi (e.g., *Metarhizium anisopliae*, *Beauveria bassiana*).
- ✓ Nucleopolyhedroviral (NPV) specific to fall armyworm.

Mechanical and Physical Control

Hand Picking: Remove and destroy egg masses and larvae (feasible in smallholder farms).

Pheromone Traps: Use for monitoring and mass trapping of male moths to reduce mating.

Light Traps: Attract and kill adult moths at night.

Chemical Control

- ✓ Use selective insecticides (e.g., spinosad, emamectin benzoate, lufenuron) that are less harmful to beneficial organisms.
- ✓ Rotate insecticides with different modes of

action to prevent resistance.

- ✓ **Threshold-based application:** Only spray when pest numbers exceed economic threshold levels (e.g., more than 10% of plants infested at early growth stage).

Genetic Control

Bt Maize: Genetically modified maize that produces Bt toxins effective against fall armyworm.

Host Plant Resistance: Develop and plant maize varieties with natural resistance to fall armyworm.

Monitoring and Decision Support

Regular field scouting to detect egg masses and early larval stages.

Farmer Education & Community Action

- ✓ Train farmers in IPM practice through Farmer Field Schools or extension services.
- ✓ Promote area-wide pest management to ensure neighboring farms collaborate for greater impact.

Conclusion

Integrated Pest Management (IPM) is the most effective and environmentally friendly strategy to manage fall armyworm. It combines multiple control methods viz., cultural, biological, mechanical, chemical and genetically based on regular monitoring and informed decision-making. By using IPM, farmers can protect their crops, reduce pesticide overuse, and maintain long-term control of the pest. Collaboration, farmer training and community action are key to its success.

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Nutraceutical Significance of Human Health from Vegetable Crops

Neha Verma, Neha Rana and Manisha Thakur

Malnutrition remains one of the most pressing global health challenges significantly contributing to illness and mortality worldwide. Protein-energy malnutrition coupled with micro-nutrient deficiencies are among the leading causes of poor health and death on a global scale (Riaz *et al.*, 2022). Although the incidence of extreme hunger has declined over the past few decades, approximately 821 million people were still chronically undernourished in 2018. According to the World Health Organization (WHO), around 210 million children and women suffer from vitamin A deficiency and nearly 45% of children under five years old are malnourished in developing countries with the highest prevalence observed in South Asia and Africa (WHO, 2022). India, despite being one of the fastest-growing economies in South Asia has struggled to combat malnutrition which has impeded its socio-economic development. Nearly half of the world's malnourished children reside in Bangladesh, India and Pakistan with India alone accounting for over one-third of them. The widespread occurrence of infectious and chronic diseases has heightened public awareness of health and nutrition leading to an increased demand for foods rich in antioxidants, proteins and essential vitamins. Since ancient times, traditional foods and herbal extracts have played a crucial role in holistic health practices particularly in

Ayurveda as well as in traditional Chinese, Roman and Greek medicine (Misra *et al.*, 2013). The Greek physician Hippocrates emphasized the concept of food as medicine famously stating, Let food be thy medicine and medicine be thy food (Helal *et al.*, 2019). Throughout history, various natural ingredients including cinnamon, saffron, honey, garlic, ginger, pomegranate and mint have been valued for their therapeutic properties and their ability to restore health and vitality (Petrovska, 2012). Vegetables being low in calories are the essential part of balanced diet since they are good source of phytonutrients and nutraceutical compounds. In everyday life, nutraceuticals have received a lot of attention because they are safe, efficient and have potential nutritional and therapeutic benefits. Different vegetables vary significantly and possess unique compositions of nutraceuticals. Nutraceutical is a term given by Dr. Stephen De Felice in 1989 and came from two words “nutrition” and “pharmaceutical” which refers to the substances that may be considered a food or part of a food which generally sold in medicinal form and have an impact on health care system (Puri *et al.*, 2022). With the growing concerns over pharmaceutical side effects and antimicrobial resistance, nutraceutical compounds have emerged as promising alternatives due to their affordability and therapeutic benefits, including

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lipid-lowering, anti-inflammatory, anti-cancer, and antioxidant properties (Chen *et al.*, 2017; AlAli *et al.*, 2021). While their medicinal potential is widely recognized, more high-level clinical trials are needed to ensure long-term safety and efficacy. Clear differentiation between their role as medicine or essential nutrients is crucial, along with advanced research on their bioactivity and bioavailability. Vegetables are excellent sources of essential vitamins (ascorbic acid, folic acid), minerals (iron, calcium, phosphorus), antioxidants, fibres, proteins and carbohydrates contributing significantly to disease prevention and health maintenance. In India, a wide range of vegetables such as asparagus, brinjal, broccoli, Brussels sprouts, capsicum, chili, Chinese cabbage, cucurbits, green beans, lettuce, okra, peas, spinach and tomatoes are cultivated on a commercial scale. Vegetables packed with nutraceuticals can play a crucial role in overcoming malnutrition and achieving nutritional security through sustainable and cost-effective means. As per WHO recommendations, 400 grams of vegetables should be consumed daily as part of a balanced diet to maintain overall well-being. Several nutraceuticals, including lycopene, glucosinolates, quercetin, folates, silymarin, kaempferol, luteolin, apigenin and alliin are present in specific vegetables and have been found effective in preventing and managing various diseases such as cancer, diabetes, hypertension and high cholesterol. The availability of diverse and highly nutritious vegetables presents a promising approach to addressing malnutrition and ensuring a healthier future.

Various methods, including agronomic techniques, conventional breeding, molecular breeding, marker-assisted selection and genetic modification through genome editing have been employed to develop nutraceutical-rich vegetables. Among these, agronomic techniques such as seed treatment, foliar application and the use of organic manures are commonly used to enhance the nutraceutical value of vegetable crops. These approaches are relatively inexpensive and offer quicker results compared to other improvement methods. However, for a more sustainable and long-term solution conventional breeding methods such as selection, introduction and hybridization have played a significant role in developing biofortified varieties with enhanced nutritional value. In India, several biofortified vegetable and tuber crop varieties have been developed and released through traditional breeding approaches incorporating higher levels of essential nutrients and bioactive compounds. For instance, nutritionally enriched carrot varieties like Punjab Black Beauty, Pusa Asita and Pusa Rudhira have been developed with higher anthocyanin content, while Kashi Lalima in okra and Pusa Gulabi and Pusa Jamuni in radish are rich in antioxidants. Similarly, Palam Vichitra in broccoli and Kinner Red in cabbage have been bred for enhanced phytochemical content and Pusa Beta Kesari 1 in cauliflower has been developed for improved beta-carotene levels. In tuber crops, varieties such as Sree Kanaka, Bhu Sona and Bhu Krishna in sweet potato, Sree Visakham in cassava and Punjab Magaz Kadoo-

Table 1: List of some common nutraceuticals isolated from vegetable crops

Sr No	Vegetable Crops	Nutraceuticals (Chemical compound)	Properties
1.	Onion and Garlic	Allyl propyl disulfide, Quercetin, Alliin, Methiin	Antifungal, antibacterial, antioxidant, used to treat arteriosclerosis
2.	Carrots, pumpkins, sweet potatoes, winter squash, broccoli, spinach and kale	Beta carotene	Antiaging, anticancerous, improve lung function, reduce complications associated with diabetes
3.	Red Chilli	Capsaicin	Used for pain relief topically and as a digestive aid when taken internally, antioxidant, antiallergic
4.	Carrot	Caffeic acids	Inhibitor of the lipoxygenase enzyme that forms leukotrienes from arachidonic acid
5.	Broccoli, carrot, celery, onion	Tocopherol	It is a fat-soluble antioxidant that stops the production of reactive oxygen species formed when fat undergoes oxidation
6.	Tomato	Lycopene	Anticancer
7.	Brinjal and red cabbage	Proanthocyanin	Help in urinary tract infections by inhibiting adhesion of microorganisms like <i>E. coli</i> to the urinary tract wall
8.	Red Onion	Resveratrol	Anticancer (skin and breast cancer), anti-ageing
9.	Cole crops	Glucosinolates, sulforaphane, vitamin C, luteolin, apigenin	Breast cancer, stomach and lung cancer
10.	Broccoli	Sulphoraphane	Used against breast cancer
11.	Turnip and Rutabaga	Glucorucin and glucoraphanin	Cancer and heart diseases
12.	Beet root	Ferulic acid and betanin	Skin disease, antiageing
13.	Legume vegetables	Isoflavonoids	Osteoporosis and obesity and menopause
14.	Okra	Quercetin and flavonol derivatives	Diabetes and Vitality
15.	Celery	Luteolin, apigenin, butylphthalide	Cancer of breast, skin, used in high blood pressure
16.	Sweet Potato	Anthocyanin, chlorogenic acid	Antidiabetic, antiobesity
17.	Spinach	Patuletin and spinacetin	Weight loss, good eye sight
18.	Turmeric	Curcumin	Anticancerous, antioxidative

1 in pumpkin have been released with superior nutraceutical properties. These biofortified varieties serve as vital genetic resources for improving dietary nutrition and addressing micronutrient deficiencies, complementing agronomic and molecular breeding efforts in enhancing vegetable crop quality. Therefore, the integration of nutraceutical-rich vegetables into daily diets presents a sustainable and cost-effective strategy to combat malnutrition and improve global health. As research advances in plant breeding, molecular biology and agronomic innovations the development of biofortified vegetable varieties will continue to play a crucial role in addressing micronutrient deficiencies and promoting

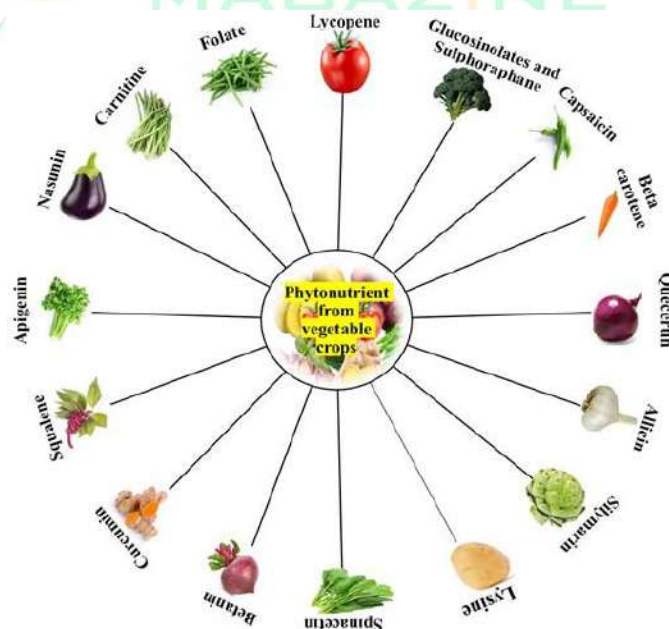
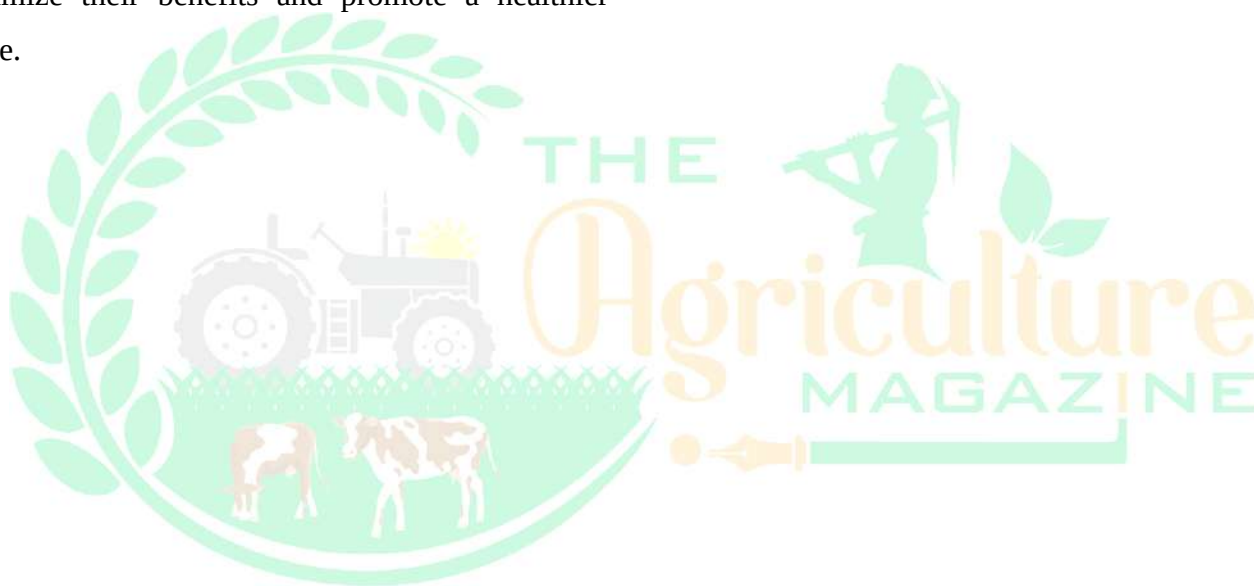


Fig. 1: Phyto-chemicals procured from vegetable crops used as nutraceutical
dietary diversification. Strengthening awareness,

accessibility and affordability of these nutrient-dense vegetables is essential for achieving long-term nutritional security to have the potential required to handle hunger and malnutrition issues. Being an eco-friendly and cost-effective possible solution to combat these issues, there is a dire need to develop, produce and to popularize these crops for human consumption so as to prevent and control various health issues. Going forward, collaboration between scientists and nutritionists will be essential to maximize their benefits and promote a healthier future.



Climate Change: Impact and Mitigation Strategies in Vegetable Cultivation

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Climate change is the greatest concern of mankind in the 21st century. Due to variability in climate parameters, India is estimated to lose around 1.5 per cent of its GDP every year. The change in climate parameters like rise in atmospheric temperature, changes in precipitation patterns, excess UV radiation and higher incidence of extreme weather events like drought, salinity and floods are major threats for vegetable production. Beside this, anthropogenic air pollutants such as CO₂, dioxides of nitrogen and sulphur, CH₄, and CFC are contributing to the global warming as well as causing depletion of ozone layer and permitting the entry of harmful UV rays. This directly affects the crop physiology and indirectly alters pest and disease dynamics, which in turn affects crop yield and quality. Vegetables are known as protective food as they supply the essential nutrients, vitamins, minerals and play an important role in ensuring food and nutritional security. The changes in weather and climate are likely to affect the food security of developing world where a large fraction of ever-increasing population is already facing hunger, insecure and unhealthy food. Vegetables are also good remunerative to the farmer as they fetch higher price in the market but due to change in climate there is subsequently decrease in yield and quality of vegetable.

As variation in climate affect normal growth, flowering, pollination, fruit set, as well as increases the incidence of insect-pest and disease and development of physiological disorder, all these factors render the cultivation of vegetable unprofitable (Fig. 1). This ultimately questions the availability of nutrient source in human diet.

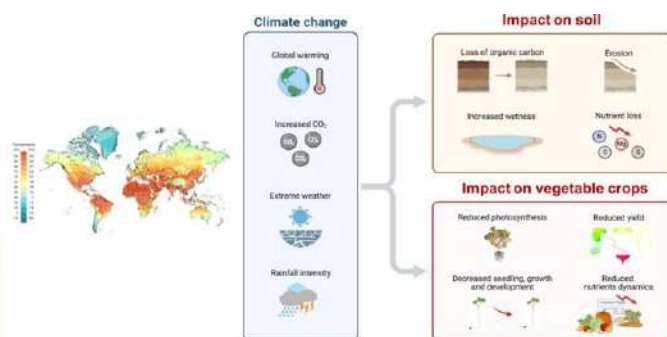


Fig. 1: Climate change impact on vegetable crops

According to IPCC report, the average global temperature has increased by 0.85°C in past decades and is predicted to increase further by 1.6-5.8°C, while CO₂ concentration has increase by 410 ppm and is predicted to increase further in range 550 to 850 ppm at end of 21st century. Annual maximum and minimum temperature are expected to increase 2-3°C by 2020-2050. Increase in CO₂ may increase the crop yield initially due to increased CO₂ fertilization, but will ultimately lead to a declined in production after some extent. It has been reported that due to global warming, there has been a decrease of 41% yield in vegetable crops since 1965 to 2016.

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Table 1: Vegetable varieties/Hybrids against various stress tolerance released in India for cultivation

Crop	Variety	Stress tolerance
Tomato	Pusa Sheetal	Fruit set up to 8°C (low) night temperature
	Pusa Hybrid 1	Fruit set up to 28°C (high) night temperature
	Pusa Sadabahar	Fruit set occurred at both low (6°C) and high (30°C) night temperatures
	Sabour Suphala	Salt tolerant at seed germination stage
	Arka Vikas	Tolerant to moisture stress
Eggplant	SM-1, SM-19 and SM-30	Drought
	Pragati and Pusa Bindu	Salt tolerance
Okra	Pusa Sawani	Tolerant to salinity
Muskmelon	Jobner 96-2	High soil pH
Cucumber	Pusa Barkha	Tolerant to high temperature
	Pusa Uday	Suitable for throughout the year
Bottlegourd	Pusa Santusthi	Hot and cold set variety
Onion	Hisar-2	Tolerant to salinity
Carrot	Pusa Kesar, Pusa Vrishti	Tolerant to high temperature
Radish	Pusa Himani	Grown throughout the year
	Pusa Chetki	Better root formation under high temperature
Sweet Potato	Sree Nandini	Drought tolerant
Potato	Kufri Surya	Heat tolerant up to 25°C night temperature
	Kufri Sheetman, Kufri Dewa	Frost tolerant
Cassava	H-97, Sree Sahya	Drought tolerant
Early cauliflower	Pusa Meghna	Form curd at high temperature

Table 2: List of potential rootstocks against various abiotic stresses

Crop	Potential Rootstock
Low Temperatre	
Cucumber	Fig leaf gourd (<i>C. ficifolia</i>), Bur cucumber (<i>Sicos angulatus</i> L.)
	Cucumber scion grafted onto squash rootstock (<i>C. moschata</i> Duch)
Watermelon	Shin-tosa-type (Interspecific squash hybrid <i>C. maxima</i> × <i>C. moschata</i>)
Flooding	
Egg plant	<i>Solanum torvum</i> , EG195 or EG203, PP0237-7502, PP0242-62
Pepper	Chili accessions PP0237-7502, PP0242-62 and Lee B
High Temperature	
Cucumber	Shintoza (<i>C. maxima</i> × <i>C. moschata</i>)
Chilli	<i>C. annuum</i> cv.Toom-1 and 9852-54(AVRDC)
Salinity	
Watermelon	TZ (148) (<i>C. maxima</i> × <i>C. moschata</i>)
Cucumber	Chaojiqianwang (<i>C. moschata</i>)
Brinjal	<i>S. torvum</i>
Drought	
Egg plant	<i>Solanum macrocarpum</i> , <i>Solanum gilo</i> , PKM-1
Tomato	<i>Solanum pennelli</i> , <i>Solanum chilense</i>
Pepper	Atlante, C-40, Serrano, PI-152225, ECU-973, BOL-58 and NuMex Conquistador

For instance, potato production increased by 11.12 per cent at elevated CO₂ of 550 ppm and 1°C rise in temperature but further rise in temperature to 3°C and CO₂ @ 550 ppm will result in 13.72 per cent decline in potato production by 2050. Thus, to achieve the targeted production of vegetable crops in the near future, to feed the burgeoning population

across the globe there is a need to adopt climate-smart strategies that mitigate these adverse effects. This includes developing resilient varieties (Table 1) tolerant to heat, drought, salinity, floods and pests using the identified tolerant germplasm through integrated genetic, agronomic and technological interventions. These techniques will be essential to

sustain vegetable production in the face of ongoing climate change. Efficient agronomic practices such as resource conservation technologies, mulching, irrigation, nutrient management, organic farming and carbon sequestration by cropping system provides a suite of possible strategies for addressing the impacts of climate change. Grafting of a susceptible scion cultivar onto a resistant rootstock is another way to combat the impact of climate change (Table 2).

Climate smart farming practices such as resource conservation technologies, urban horticulture and climate resilient perennial vegetable cultivation (e.g., drumstick, curry leaves etc.) reduce dependence on inputs and improve sustainability. Weather forecasting models can be used to predict the possible impact of climate change on vegetable crop production and also help in framing necessary mitigation strategies. In addition, climate-smart villages, digital extension tools and risk insurance schemes for vegetable crops should be promoted. At the same time, more investment is needed in research for stress physiology, gene editing (e.g., CRISPR-Cas) and crop modeling. Collaboration between research institutions, farmers and policymakers will be vital to ensure sustainable, climate-resilient vegetable systems in the decades to come.

Biochar: A Black Gold for Sustainable Agriculture

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Introduction

When we hear the term “Biochar,” many of us may wonder what is it, and why is it gaining global attention? On one hand, biochar offers a promising solution for sustainable soil management and climate change mitigation; on the other hand, questions remain about its large-scale applicability and cost-effectiveness. As the agricultural sector grapples with issues like declining soil fertility, greenhouse gas emissions, and overuse of synthetic fertilizers, biochar is emerging as a potential game-changer. But is it really the magical solution agriculture has been waiting for? Or is it just another overhyped concept? Biochar, often dubbed as “black gold,” is a carbon-rich product obtained when organic biomass such as crop residues, wood chips, or manure is subjected to pyrolysis (a process of heating in the absence of oxygen). Unlike ash, biochar is stable, porous, and retains carbon in the soil for hundreds to thousands of years. It is not just a soil amendment; it is a soil revolution that supports plant growth, improves soil structure, increases microbial activity, and sequesters atmospheric carbon. But like every innovation, biochar too has its set of challenges and limitations that must be critically evaluated.

What exactly is Biochar?

Biochar is produced through a process known as pyrolysis, where organic biomass such as crop residues, wood chips, or animal manure is heated at high temperatures in a low-oxygen environment. This process results in a stable form of carbon that, when added to the soil, improves water retention, boosts microbial activity, and enhances nutrient availability. Unlike ordinary compost or ash, biochar has a porous structure that acts like a sponge in the soil. It traps nutrients and releases them slowly, which helps plants access nutrients more efficiently and reduces the leaching of fertilizers into water bodies. Additionally, biochar provides a favourable habitat for beneficial soil microbes, thereby improving plant health and growth. Importantly, biochar plays a key role in mitigating climate change. According to a 2023 global scientific report, each ton of biochar added to the soil has the potential to sequester between 1.15 to 3.3 tons of carbon dioxide equivalents, depending on the feedstock and method used. A worldwide assessment in 2022 estimated that large-scale adoption of biochar could help remove up to 3 billion tons of CO₂ annually from the atmosphere, making it one of the most scalable

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carbon removal options available. In the Indian context, the opportunity is substantial. As per estimates from the Ministry of Agriculture in 2023, India generates nearly 156 million tons of surplus crop residues every year. These residues, if converted into biochar, could yield around 34.5 million tons of biochar annually and help sequester approximately 7.5 million tons of carbon. This would also help in curbing pollution caused by open stubble burning, particularly in states like Punjab and Haryana.

Government Efforts in Promoting Biochar

Recognizing the dual benefits of biochar for agriculture and climate, several government departments and research institutions have begun to explore and promote its use. The Indian Council of Agricultural Research (ICAR), along with institutions like the Indian Agricultural Research Institute (IARI) and the Indian Institute of Soil Science (IISS), has conducted extensive field trials over the last decade. In their 2022 reports, these institutes confirmed biochar's potential in enhancing soil fertility, increasing crop yield, and improving carbon sequestration. The National Mission on Sustainable Agriculture (NMSA), updated in 2023, also includes biochar as a key component in integrated nutrient management systems. Moreover, the Ministry of New and Renewable Energy (MNRE) has promoted the use of small-scale pyrolysis units for on-farm biomass conversion into biochar and clean energy. In March 2024, a senior Union Minister of State highlighted in a public

address that India is encouraging the use of low-cost pyrolysis units priced at approximately ₹30,000, making them accessible to smallholder farmers. He cited an example from Maharashtra where sugarcane yields improved from 60-70 tons per acre to over 100 tons per acre with biochar application. The Minister emphasized that such improvements came without increasing fertilizer use, underscoring biochar's dual value in productivity and sustainability. Internationally, organizations like the Food and Agriculture Organization (FAO) and the Intergovernmental Panel on Climate Change (IPCC) have recognized biochar as a powerful tool for climate adaptation. In the 2022 IPCC report on climate mitigation, biochar was listed among the top five carbon removal technologies with proven long-term stability in soils.

Recent Developments and Private Sector Involvement

Private sector interest in biochar has surged in recent years. According to a 2024 industry report, a major U.S.-based technology company entered a long-term contract with an Indian clean-tech startup to purchase 100,000 tons of carbon dioxide removal (CDR) credits via biochar, extending through 2030. This was part of the company's global strategy to offset emissions using nature-based and technological solutions. In India, a 2023 case study spotlighted a startup that has successfully converted over 3,000 tons of agricultural waste into high-quality biochar using torrefaction reactors in Uttar Pradesh. These closed-loop systems significantly

reduce harmful emissions and offer rural farmers a sustainable alternative to stubble burning. Academic-industrial collaboration is also taking shape. In 2024, a project initiated between the Indian Institute of Technology (IIT) Kanpur and a private steel manufacturer aimed to substitute a portion of industrial coal with biochar. Preliminary results suggest that this shift could reduce industrial carbon emissions by up to 40% over the next five years, making it a model for other energy-intensive industries.

Limitations and Concerns around Biochar

Despite its promise, biochar is not without drawbacks. The primary challenge is economic setting up efficient pyrolysis units requires capital investment, which may be out of reach for small and marginal farmers. Although traditional methods like pit kilns are cheaper, they are inefficient and emit smoke and pollutants, thus negating the environmental benefits. There's also significant variability in biochar quality. According to an IISS technical bulletin (2022), the effectiveness of biochar depends on feedstock type, pyrolysis temperature, and soil compatibility. Improperly made biochar may contain harmful residues such as polycyclic aromatic hydrocarbons (PAHs), which can inhibit microbial activity and even damage plant roots. Moreover, biochar should not be treated as a standalone input. Agricultural scientists, in a 2023 ICAR field study, stressed that biochar performs best when integrated with compost, green manures, and other regenerative practices. When used alone or in excess, its benefits

plateau or may even diminish. Another major concern is awareness. A 2023 survey conducted across five Indian states revealed that over 80% of farmers had never heard of biochar or its uses. The lack of extension services and scientific advisory at the local level hampers adoption. Without demonstrations and training, farmers are unlikely to adopt a technology they neither understand nor trust.

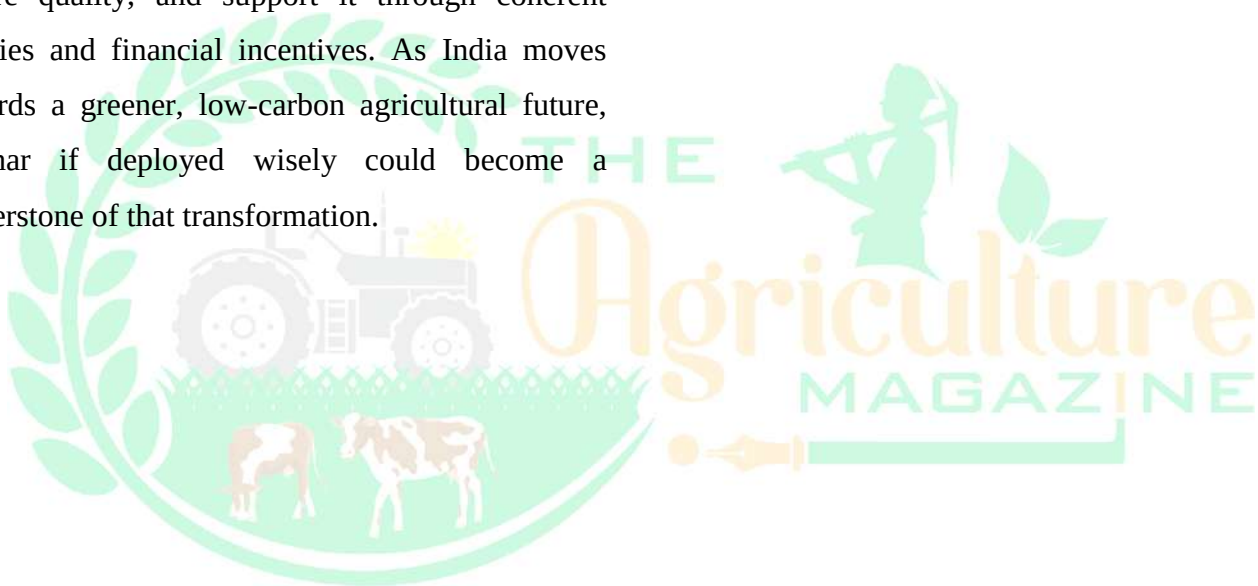
A Way Forward

To unlock biochar's full potential, a holistic and inclusive approach is necessary. Governments must prioritize subsidies for decentralized pyrolysis units and support farmer cooperatives in managing them. Training programs, mobile advisory services, and model demonstration plots should be scaled up across diverse agro-climatic zones. Quality standards and certifications must be established to ensure that only safe and effective biochar reaches the field. Research institutions should publish regional guidelines for feedstock selection, pyrolysis temperature, and soil application based on local conditions. Furthermore, biochar should be integrated into India's carbon trading framework. According to a 2023 proposal by the National Bank for Agriculture and Rural Development (NABARD), carbon credit incentives can significantly boost farmer participation in sustainable practices like biochar use. Pilot programs linking biochar use with verified carbon credits can open new income streams for farmers. Additionally, including biochar in the broader push for climate-smart agriculture will help position India as a leader in sustainable land mana-

gement and nature-based carbon removal.

Conclusion

Biochar is not a magic bullet but it is a powerful tool in the fight for sustainable agriculture and climate resilience. Its ability to enrich soils, reduce dependency on chemical fertilizers, and lock away carbon for centuries makes it uniquely suited to the challenges of our times. However, its real-world success will depend on how well we integrate it with existing agricultural practices, train farmers, ensure quality, and support it through coherent policies and financial incentives. As India moves towards a greener, low-carbon agricultural future, biochar if deployed wisely could become a cornerstone of that transformation.



Fortune Story of AI in Revolutionizing Sugarcane Cultivation

Koya Madhuri Mani and Nagender G.

Introduction

Sugarcane farmers in Maharashtra's Baramati region are embracing artificial intelligence (AI) to enhance crop yields and promote sustainable farming practices. Collaborating with the Agricultural Development Trust (ADT) of Baramati and utilizing Microsoft's AI technology, farmers receive daily guidance through a mobile app. This app offers tailored insights on irrigation schedules, precise fertilizer application and pest monitoring, all customized to specific areas of their fields. The AI-driven approach has led to significant improvements. For instance, farmer Suresh Jagtap reported greener leaves, more uniform growth, and an increase in the number of tillers per sapling from five or six to ten or more. These advancements suggest a potential increase in both crop quantity and quality. Farmers have reported substantial improvements in crop yields. For instance, the AI-driven approach has led to sugarcane stalks that are 30-40% heavier and contain 20% more sucrose, with the crop cycle reduced from 18 to 12 months. The system integrates data from various sources, including weather stations, soil sensors, and satellite imagery. This comprehensive data collection allows the AI to provide farmers with actionable advice, optimizing

conditions for peak sucrose content at harvest time. The use of AI has resulted in a 25% reduction in fertilizer usage and significant water savings through smart irrigation practices. The Agripilot.ai app provides farmers with daily, field-specific guidance on irrigation, fertilization and pest control, enhancing decision-making and reducing guesswork.



The success of this initiative has garnered attention from industry leaders. Microsoft Chairman Satya Nadella praised the project during his visit to Baramati, highlighting the transformative potential of AI in agriculture. The project's expansion from an initial 1,000 farmers to 50,000 across Maharashtra demonstrates its scalability and potential for broader impact. Additionally, companies like Mahindra & Mahindra and CultYvate are contributing to this technological shift. Mahindra has implemented AI-based harvesting technologies to assess sugar content in sugarcane, determining the optimal harvest time to

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maximize yield and sugar recovery. CultYvate has introduced smart irrigation solutions that allow farmers to control water usage via mobile apps, ensuring efficient water distribution and reducing labor requirements.

Areas for Improvement

Accessibility and Affordability: The initial investment of ₹10,000-₹12,500 for participation may be prohibitive for small-scale farmers, potentially limiting widespread adoption.

Digital Literacy: Effective utilization of AI tools requires a certain level of digital literacy, which may not be prevalent among all farmers, necessitating comprehensive training programs.

Data Privacy Concerns: The collection and use of farm data raise questions about data ownership and privacy, highlighting the need for clear policies and safeguards.

Sustainability of Support: The long-term success of the initiative depends on sustained support from technology partners and continuous updates to the AI systems to adapt to changing agricultural conditions.

Conclusion

This integration of AI into sugarcane farming not only boosts productivity but also addresses challenges like water scarcity and pest management, paving the way for a more sustainable agricultural future in Maharashtra.

Digital Platforms Enhancing Market Access for Himachal Pradesh Farmers

Kshitij Mandial, Girish Mahajan and Arushi Mandial

Introduction

Farmers in Himachal Pradesh often face challenges in accessing markets due to the state's hilly terrain and dispersed settlements. Limited connectivity and reliance on traditional marketing methods can lead to reduced income and inefficiencies. This article explores how digital platforms are improving market access for these farmers, leading to better prices and reduced losses.

Challenges in Market Access

Several factors hinder farmers' ability to reach broader markets:

Transportation Difficulties: The mountainous landscape makes it hard to transport produce quickly and efficiently.

Information Gaps: Farmers may lack up-to-date information on market prices and demand trends.

Dependence on Middlemen: Without direct access to buyers, farmers often rely on intermediaries who may offer lower prices.

Digital Solutions Making a Difference

The introduction of digital tools is helping to address these issues:

Online Marketplaces: Platforms like the National

Agriculture Market (eNAM) allow farmers to sell directly to buyers, reducing the need for intermediaries.

Mobile Applications: Apps provide real-time data on market prices, weather forecasts, and best practices, enabling farmers to make informed decisions.

Digital Payments: Electronic transactions ensure timely and secure payments, fostering trust between farmers and buyers.

Case Study: Apple Growers in Kullu District

In Kullu district, apple farmers began using a mobile application to connect directly with urban retailers. This initiative led to:

Higher Earnings: Farmers reported a 25% increase in income due to better pricing.

Reduced Waste: Timely sales minimized post-harvest losses.

Improved Planning: Access to market trends helped farmers make better cultivation and sales decisions.

Role of Educational Institutions

Institutions like CSKHPKV Palampur and YS Parmar University are instrumental in this trans-

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formation:

Research and Development: Creating user-friendly digital tools tailored to local needs.

Training Programs: Educating farmers on how to effectively use technology for market access.

Policy Advocacy: Working with policymakers to support the development of digital infrastructure in rural areas.

Conclusion

Digital platforms are proving to be valuable tools for farmers in Himachal Pradesh, enhancing market access and increasing income. Continued collaboration between educational institutions, government bodies, and the farming community is essential to expand these benefits and support sustainable agricultural development.

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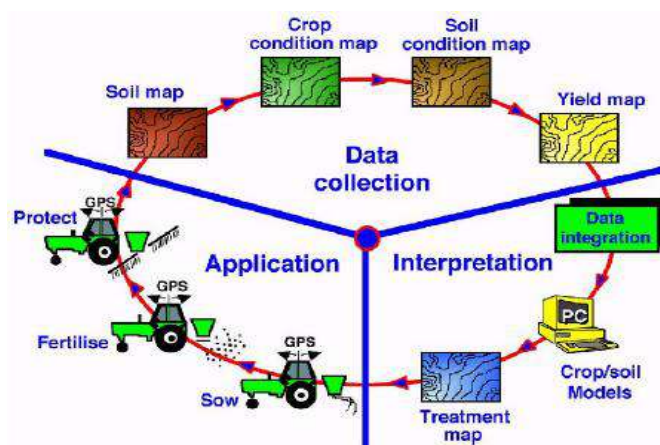
Precision Agriculture in India

Sanjana Chauhan, Ankit Kumar and Jagvir Singh

Introduction

The agriculture is a backbone of Indian's economy. Because more than 70% population is engaged in agriculture field and raw material for the industrial sector like as food processing companies etc. Now-days advancement is more significant in agriculture sector. The precision agriculture is part of advancement and it merges new technologies. The goal is not new but new technologies now available allow the concept of precision agriculture to be realized in a practical production setting (Tejashree, 2020). Precision agriculture is also known as precision farming. It is a farming approach that uses modern technologies to optimize crop production, resource use, increase efficiency and improve crop yield. It is a combination of different technologies. Precision agriculture or farming is based on the Site specific nutrient management. It is about doing the right input, right place, right rate, right time and right manner. It helps to managing crop production like as water, seed, fertilizer etc. to increase crop yield, quality and profit. The precision agriculture began to gain attention in India with the introduction of GPS technology and satellite imagery. In this period, the Indian government, along with research institution,

started exploring ways to use technology for better land management, irrigation system and crop monitoring (Kumaresan, 2024).



Need of precision agriculture in India

- ✓ Farmers facing many challenges related to crop production, water scarcity, climate changes and soil health.
- ✓ The Indian Council of Agricultural Research (ICAR) has initiated a Network Project focused on precision agriculture.
- ✓ Numerous private dairy farms are adopting an RFID-based animal identification and farm automation management system.
- ✓ Indian government promotes precision agriculture through the establishment of 22 Precision Farming Development Centers (PFDCs).
- ✓ Additionally, educational institutions and research

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ch centers organizing workshops and training programs provide knowledge to farmers (Anonymous, 2024).

Some essential components of precision agriculture

Global Positioning System (GPS): GPS technology used to pinpoint the location of farm equipment in the field. It is a set of 24 satellites in the earth orbit which allows GPS receivers to calculate their position. It helps to monitor crop conditions using a network of orbiting satellite that send the location details from earth to space.

Geographical Information System (GIS): GIS is software that imports, exports and processes spatially and temporally geographically distributes data. GIS contributes significantly to precision agriculture by allow the presentation of spatial data in the form of a map. It is crucial information tools the producer has to store, retrieve, analyze map and manage all agricultural data

Remote sensors (RS): Remote sensing can be defined as the collection of data about an object from a distance without coming in contact with it. Remote sensing has been used in soil mapping, terrain analysis, crop stress, yield mapping and estimation of soil organic matter, but on a scale larger than what is required for precision agriculture. It is the process of acquiring information about the earth's surface by measuring its reflected and emitted radiation without coming into direct contact with the object.

Satellite Imagery and Aerial Drones: These technologies provide real-time data on crop health,

pest and disease infestations, and overall field conditions, enabling timely interventions (Sahoo *et al.*, 2015).

Yields mapping and monitoring: They produced by processing data from adapted combine harvester that is equipped with a GPS, i.e. integrated with a yield recording system. Yield mapping involves the recording of the grain flow in actual location in the field at the same time through the combine harvester.

Variable rate technology (VRT): Variable Rate Technology (VRT) includes computer controllers that allow variation of inputs such as seed, fertilizer, herbicides and pesticides. Application rates are varied as areas of different potentials or problems warranting different rates are encountered.

Variable Rate Fertilization: VRT adjusts fertilizer application rates based on soil nutrient levels, resulting in improved nutrient management and reduced over application.

Variable Rate Seeding: VRT optimizes seed placement based on soil and yield data, increasing crop uniformity and yield potential (Birthal and Dadlani, 2022).

Benefits of Precision Farming

Enhanced Agricultural Productivity: Precision agriculture increases agricultural output and promotes crop yield by using precise amount of inputs such as water, fertilizers etc.

Reduction in Chemical Application: Use of proper amount of fertilizer at the right time, reduction in waste supply of fertilizers.

Prevention of Soil Degradation: Due to avoiding

overuse of chemicals, precision farming inhibits the leaching of unnecessary chemicals into the soil which help to protect soil health.

Efficient Use of Water Resources: It helps to reduce water use through target delivery technique like as fertigation.

Improved Farm Income: It can help to improve farm income and raise the economic conditions of farmers by increment in productivity and diminishing use of inputs and wastage.

Job Creation: It has potential to create employment opportunity for people. For example- drone operating is a specialized skill. People can be trained and employed as certified drone operators (Greena *et al.*, 2015).

Challenges in Precision Agriculture

High Cost: Precision Agriculture is costly for adaptation due to technologies like as GPS, drones and sensors.

Lack of Technical Expertise and Technology: Use of technology should be careful because it requires high level of awareness and skills.

Security Risk: Precision agricultural practice is a part of technology so they have security risk. The technologies behind precision practices open up opportunities for terrorists and adversarial govt. to attack farming machinery with the aim of disrupting food production.

Data Collection: The prevalence of segregated smallholder farms in the country complicated the process of data gathering.

Lack of Centralized Repository: A centralized

repository is needed to store data from different geographical locations, weather conditions, soil types, crop types and other parameters to create a viable model based on advanced technology (Tejashree, 2020).

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Integrated Pest Management Strategies for Whitefly (*Bemisia tabaci*) Management in Greengram

Richa Gupta, Ayush Kumar, Preeti Yadav, Anshuman Singh and C. P. N. Gautam

Abstract

Whiteflies (*Bemisia tabaci*) severely impact mung bean (*Vigna radiata*) through direct feeding, sooty mold and virus transmission. Integrated Pest Management (IPM) combines eco-friendly strategies for sustainable control. Cultural methods include crop rotation, early sowing and intercropping with repellent plants like marigold. Biological control relies on natural enemies (*Encarsia formosa*, *Beauveria bassiana*) and biopesticides. Mechanical control involves yellow sticky traps and vacuuming. Chemical control should be minimal, using selective insecticides (neonicotinoids, pyriproxyfen) only at economic thresholds to prevent resistance. Host plant resistance, through whitefly-tolerant varieties, reduces infestation. Farmer awareness of pest scouting and threshold-based spraying ensures effective implementation. Combining these tactics reduces whitefly populations, enhances yield and minimizes pesticide reliance, promoting sustainable mung bean production.

Introduction

Green gram (*Vigna radiata* L. Wilczek), commonly called mung bean, is a highly nutritious, self-pollinating legume containing 24.5% protein, with high lysine and tryptophan content. When sprouted, it produces ascorbic acid (Vitamin C). As one of the earliest cultivated pulses, it adapts well to diverse climates but thrives best in warm, humid conditions with adequate rainfall and optimal temperatures. It is a protein-rich pulse crop, faces significant yield losses due to biotic stresses, particularly insect pests. Chandra and Rajak (2004) documented 11 insect pest species infesting *Vigna mungo* (a closely related species) in Uttar Pradesh's

Faizabad and Lucknow districts, prominence the threat posed by insect infestations to green gram production. Sucking pests are a serious problem in mungbean cultivation, with whitefly, aphid, jassid, and thrips being the primary culprits (Singh *et al.*, 2024). Among them, whiteflies (*Bemisia tabaci*) are highly destructive pests of mungbean, causing both direct and indirect damage. Their phloem-feeding weakens plants, while excreted honeydew promotes sooty mold growth, reducing photosynthesis (Singh *et al.*, 2024). More critically, they transmit devastating viruses like Mungbean yellow mosaic virus (MYMV). Symptoms begin as small yellow spots on leaves, progressing to irregular yellow green patches.

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Severe infections lead to stunted growth, undersized seeds, and yield loss. Early-stage feeding also causes leaf curling and blistering, further reducing plant vigor.



Fig. 1(a): Severe infestation of whitefly



Fig. 1(b): MYMV Incidence by whitefly

IPM strategies for whitefly management

Cultural Practices

- ✓ Rotate with non-host cereals (maize, sorghum) for 2-3 seasons.
- ✓ Sow during early June to escape peak infestation (varies by region)
- ✓ Intercrop with marigold (*Tagetes* spp.) at 1:10 ratio (marigold:mungbean)
- ✓ Grow tolerant varieties like SML 668, IPM 2-3 where available.

Physical Methods

- ✓ Install 25×20 cm yellow sticky traps @ 50 traps ha⁻¹.
- ✓ Use 40-50 mesh insect-proof nets for nursery protection.

Sanitation

- ✓ Remove weeds (especially *Parthenium*, *Abutilon*) within 50 m radius.
- ✓ Deep plough infested residues immediately after harvest.

Biological Control

- ✓ Release *Encarsia formosa* @ 5,000-10,000 wasps ha⁻¹ at first whitefly sighting.

- ✓ Apply *Beauveria bassiana* (1×10⁸ CFU g⁻¹) 5 g liter⁻¹ water, 500 L ha⁻¹.
- ✓ Spray neem oil (5% EC) @ 3-5 ml liter⁻¹ at 15-day intervals.

Chemical Control

- ✓ Imidacloprid 17.8 SL @ 0.3 ml liter⁻¹ (waiting period 15 days).
- ✓ Acetamiprid 20 SP @ 0.2 g liter⁻¹ (waiting period 10 days).
- ✓ Pyriproxyfen 10 EC @ 0.5 ml liter⁻¹ (IGR, safest option)
- ✓ Spiromesifen 22.9 SC @ 1 ml liter⁻¹ (anti-feeding action)

Conclusion

Whiteflies (*Bemisia tabaci*) cause severe damage to mungbean crops through direct feeding, sooty mold formation and transmission of destructive viruses like MYMV, resulting in substantial yield reduction. Implementing integrated pest management combining cultural practices, biological control and judicious chemical use is crucial for effective and sustainable whitefly control in mungbean cultivation.

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Integrated Pest Management Strategies for Sesame Leaf Roller (*Antigastra catalaunalis* Dup.)

Richa Gupta, Preeti Yadav, Anshuman Singh, Ayush Kumar and C. P. N. Gautam

Abstract

Sesame is a key oilseed crop affected by major pests like the leaf roller and capsule borer (*Antigastra catalaunalis*), leading to significant yield losses. An Integrated Pest Management (IPM) approach offers an eco-friendly and sustainable solution. This strategy combines timely sowing, intercropping, and removal of infested parts (cultural methods), along with mechanical control through hand-picking. Biological control involves releasing natural enemies like *Trichogramma* spp. and *Chrysoperla carnea*. Botanical insecticides such as neem seed kernel extract and neem oil are effective in reducing pest populations. Selective chemical sprays like spinosad or emamectin benzoate are applied only when necessary. Overall, IPM effectively reduces pest pressure, promotes ecological balance, and enhances sesame yield in a cost-effective and environmentally safe manner.

Introduction

The sesame plant (*Sesamum indicum* L.) is one of the earliest oilseed crops in India belonging to Pedaliaceae family. There are several more names for the till, including gingelly, simsim, beniseed, safed til, kala til and tillie. Sesame is renowned as the “Queen of Oilseeds” due to its massive yield and high-grade oil. Most of the sesame crops in the nation are utilized for oil extraction (70-75%), a significant percentage is used up as food approximately (20-25%) and a very little proportion (2.2%) is saved as seed. Calcium, iron and phosphorus are among the minerals found in sesame seeds, which also comprise 46 to 50% oil and 25% protein. Its oil has a higher concentration of unsaturated fatty acids viz., linoleic acid (37-47%), oleic acid (35-43%), palmitic acid (9-

11%) and stearic acid (5-10) (Mishra *et al.*, 2023).



Fig. 1(a): Leaf damage caused by *Antigastra catalaunalis* (Dup.)



Fig. 1(b): Plant damage caused by *Antigastra catalaunalis* (Dup.)

Sesame production potential has not been fully achieved due to various abiotic and biotic factors. Among the biotic factors, insect pest's invasion is mainly responsible for limiting the yield. At various growth stages, sesame plants are attacked by 29 insect pests (Biswas *et al.*, 2001), with *Antigastra catalaunalis* (Lepidoptera: Crambidae) being one of the most destructive in India. This pest, known as the sesame leaf roller and capsule borer,

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affects all plant parts except the roots. Larvae feed on tender leaves by webbing the upper foliage during early growth, attack flowers during blooming, and bore into developing seeds during the capsule stage (Mishra *et al.*, 2023). Early infestation can kill the plant, while late infestation hampers shoot growth. If infestation occurs at a later stage, growth of the infested shoot gets affected. Single larva can destroy two to three plants in a week. *A. catalaunalis* can cause up to 90 per cent yield losses (Ahuja and Bakhetia, 1995).

Integrated pest management strategies for sesame leaf roller and capsule borer

- ✓ Timely sowing to avoid peak periods of pest infestation.
- ✓ Intercropping with pigeon pea or cowpea to reduce pest incidence.
- ✓ Removal and destruction of infested shoots and capsules.
- ✓ Regular monitoring of crops for pest population and damage symptoms.
- ✓ Hand-picking and destruction of larvae and egg masses.
- ✓ Installation of pheromone traps to monitor adult moth activity.
- ✓ Avoid repeated use of the same insecticide to prevent resistance.
- ✓ Training and awareness programs for farmers on pest identification and IPM techniques
- ✓ Release of *Trichogramma* spp at appropriate intervals.
- ✓ Conservation of natural enemies like *Chrysopa-*

rla zastrowi sillemi and ladybird beetles.

- ✓ Spraying neem seed kernel extract (NSKE) 5% or neem oil 2% during early stages of infestation.
- ✓ Need-based application of Spinosad 45% SC or Emamectin Benzoate 5% SG when pest crosses ETL.

Conclusion

Integrated Pest Management (IPM) for *Antigastra catalaunalis* in sesame effectively combines cultural, biological, and chemical methods to sustainably reduce pest populations and minimize crop damage.

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Aphids as Vectors of Plant Viruses: Mechanisms, Transmission and Impact

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The insect group known as aphids represents one of the biggest and most diverse collections of species numbering at 4,000 described varieties. The majority of aphid species consume plant sap but a specific group of these insects serves as essential vectors for transmitting plant viruses. The more than 400 aphid species contain 150 vector species that transfer 90 different plant viruses. Among all aphids, *Myzus persicae* stands out as the green peach aphid that spreads more than fifty different plant viruses. This paper examines how aphids interact with viruses throughout history while investigating their feeding procedures and transmission pathways and disease effects from vector-borne infections.

History of Aphid-Transmitted Viruses

The connection between aphids and plant viruses dates back over a century. In 1914, Allard first demonstrated that *Myzus persicae* was capable of transmitting Tobacco mosaic virus, one of the first plant viruses to be discovered. This was followed by several other significant findings:

1920: Doolittle identified *M. persicae* as a vector of cucumber mosaic virus.

1920: Brandes linked *Aphis maidis* to the transmission of sugarcane mosaic virus.

1920: Tagger reported that *M. persicae* was also

responsible for transmitting lettuce mosaic virus.

1925: Jones observed that *Macrosiphum pisi* (the pea aphid) transmitted pea mosaic virus.

These early discoveries laid the foundation for our understanding of aphids as viral vectors, shaping the course of plant pathology research.

Aphid Feeding Behavior and its role in Virus Transmission

Aphids use needle-shaped stylets to penetrate plant tissues in order to obtain sap. The feeding process enables their survival while facilitating virus transmission to plants. Aphids execute their complex feeding process through these following steps:

- ✓ The aphid's stylet penetrates plant tissue through intracellular penetration when it encounters plant tissue. The stylet needs 42 seconds to penetrate the plant tissue during the initial stage.
- ✓ The stylet requires two minutes to reach the mesophyll before aphids focus their feeding activity in this region. The penetration process becomes slower as the aphid needs nine minutes to get to the vascular tissue.
- ✓ The stylet requires about 10 minutes to reach the phloem tissue for aphids to extract their nutrient-rich sap.
- ✓ The stylet stays inside the plant tissue for up to

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30 minutes by rotating and twisting to enhance the feeding process.

Through rotational twisting the aphid maintains attachment to the plant for virus acquisition and inoculation during an extended period.

Virus Transmission Mechanisms

The process of virus transmission through aphids occurs through multiple intricate steps. The virus transmission occurs when aphids consume plant sap that contains the virus particles located within the phloem tissue. The virus moves through the aphid digestive system until it reaches the gut before entering the haemocoel which functions as the insect circulatory system. The virus enters particular tissues after leaving the haemocoel before reaching the salivary glands. The aphid transfers the virus to another plant while feeding through its saliva that emerges from the stylet during penetration. The inoculation process occurs throughout vascular and non-vascular tissues based on the specific virus-varieties and aphid species. Different viruses require different lengths of time between their acquisition by the aphid and their transfer to a new host (incubation period). This incubation period spans from hours to days.

Key Aphid-Vectored Diseases

Aphids are responsible for spreading a wide variety of plant viruses, causing significant agricultural damage. Some of the most notable diseases transmitted by aphids given in Table 1.

Modes of Virus Transmission

Aphids transmit plant viruses through differ-

Table 1: Modes of viruses transmission

Aphid Species	Viruses Transmitted
Green Peach Aphid (<i>Myzus persicae</i>)	Tobacco rosette virus
	Vein Distortion Virus
	Yellow net virus
	Yellow vein virus
	Barley yellow dwarf virus
	Bean leaf roll virus
	Cucumber mosaic virus
	Pea enation mosaic virus
Cotton Aphid (<i>Aphis gossypii</i>)	Barley yellow dwarf virus
	Bean leaf roll virus
	Tomato yellow top virus
	Cucumber mosaic virus
Cowpea Aphid (<i>Aphis craccivora</i>)	Tomato yellow vein virus
	Groundnut rosette virus
	Clover enation virus
Cabbage Aphid (<i>Brevicoryne brassicae</i>)	Broccoli necrotic yellows virus
	Radish mosaic virus
Banana Aphid (<i>Pentalonia nigronervosa</i>)	Banana bunchy top virus
	Cardamom katte virus

ent transmission methods which scientists have grouped according to the time span and degree of contact duration.

Non-persistent Transmission

Acquisition Period (AP): 15 seconds

Incubation Period (IP): 15 seconds

Retention Period: Minutes to hours

The transmission of viruses through aphids occurs rapidly since the acquisition and transmission process happens in minutes without any hidden latent phase. The transmission method that many aphid-borne viruses use including Potato Virus Y and Cucumber Mosaic Virus belongs to this category.

Semi-persistent Transmission

AP: 30 minutes

IP: 15 minutes

Retention Period: Hours to days

The retention of viruses lasts longer but aphids need to feed for an extended duration before

they acquire and transmit viral infections. The transmission of Cauliflower Mosaic Virus and Beet Yellows occurs through the semi-persistent mode.

Persistent Transmission

AP: 30 minutes

IP: 15 minutes

Retention Period: Days to weeks

The virus circulates inside aphids through complex biological processes that enable retention for the entire lifespan of the insect. The transmission of Barley Yellow Dwarf Virus and Potato Leaf Roll Virus occurs through this persistent virus transmission method.

Bimodal Transmission

Involves both non-persistent and semi-persistent transmission modes, as seen with Cucumber Mosaic Virus (CMV), which can be transmitted by both *Myzus persicae* (non-persistent) and *Brevicoryne brassicae* (semi-persistent).

Conclusion

Aphids are key vectors of plant viruses, spreading diseases that harm crops globally. Their feeding process allows them to acquire and transmit viruses to healthy plants. Different viruses have different transmission methods, ranging from rapid to long-lasting. Understanding aphid-virus interactions is essential for controlling these pests and protecting crops. Effective management can help reduce the agricultural damage caused by aphid-borne diseases.

Nanotechnology in Agriculture: A Tool for Enhancing Crop Production

Saoud Khan, Shivanshi and Simran Raj

Introduction

Nanotechnology is showing potential as a technique for agricultural progress. Materials that are at least 100 nanometers in size have special mechanical, optical, magnetic and electrical characteristics. Additionally, they are quite reactive due to their high surface area-to-volume ratio. Through the application of nanotechnology in agriculture, effective disease diagnosis and control are made possible, precision farming is made possible by nanosensors, productivity is increased by nanopesticides and fertilizers, and food quality and safety are boosted by creative packaging materials. In order to satisfy the evolving demands and areas of supplying food to the world's expanding population, nanotechnology is therefore crucial in agriculture.

Applications of Nanotechnology in Agriculture

Nanotechnology has become a potent toolkit in agriculture and food systems, enabling increased productivity, resistance to disease and pests, nutrient absorption, and food safety. The following are some significant uses of nanotechnology throughout the value chain of crop production:

Slow-Release Nano-fertilizers: Since most applied nutrients are squandered and pollute the environment, conventional fertilizers have low nutrient usage efficiency.

- ✓ Fertilizers using nano-encapsulation regulate the

rate of nutrient release over time to meet the needs of the crop.

- ✓ Delivering nutrients slowly and steadily lowers losses. Additionally, nanocarriers shield nutrients from soil immobilization.

Nano-pesticides: In comparison to traditional pesticides, nanoscale pesticide formulations improve solubility, dispersion, target-specific delivery, and efficiency.

- ✓ The delayed and continuous release of active substances is made possible by nanocapsules, nanogels, and emulsions.
- ✓ Lower dosages work well and cause less toxicity.

Smart Nano-Sensors for Precision Farming: Real-time monitoring of soil quality, crop growth conditions, plant diseases, moisture levels, and other factors is possible with miniature optical, electrochemical, and magnetic nanosensors. With the aid of networked nano-sensors, farmers can act quickly and transition to precision agriculture.

Smart delivery systems: Effectiveness is increased when genes, DNA, growth hormones, herbicides, and other agrochemicals are delivered to plants in a regulated and targeted manner using nano-porous zeolites, carbon nanotubes, cellulose nanofibers, and other smart carrier systems.

Antimicrobial Nano-coating: Microbial accumulation is avoided by using silver nanoparticles as

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coatings to irrigation pipes, plastic films, and greenhouse glass. This keeps farming infrastructure from deteriorating and increases its longevity.

Water purification: Water can be quickly cleaned of contaminants such as pesticides, fertilizers, and pathogens using magnetic nanoparticles, carbon nanotubes, and nanofilters. The water can then be safely repurposed for irrigation.

Plant disease diagnostics: Compared to traditional methods, nano barcodes and antibody-coated nano-probes can identify plant pathogens like bacteria and viruses more rapidly and precisely. Early illness prevention is made easier by rapid diagnoses.

Seed germination: By piercing the thick seed coat and boosting enzyme metabolism, nano priming seeds with zinc, titanium dioxide, and silica nanoparticles accelerates germination rates and plant growth.

Food packaging: When compared to traditional polymer packaging, nanocomposite films containing cellulose nanofibers and nano clays enhance the mechanical strength, barrier qualities, heat resistance, and biodegradability of food packaging.

Crop protection: Plants are protected from intense UV rays and high temperatures by silica nanoparticles sprayed to their leaves. Fruits with nano-coatings slow down ripening and avoid spoiling while being stored by limiting the passage of air and moisture.

Key Challenges of Nanotechnology in Agriculture

Despite its many advantages, there are still several major obstacles preventing the widespread

use of nanotechnology in agriculture:

Toxicity concerns: More research using life cycle studies is needed to assess how nanomaterials affect human health, microbial activity, and soil quality. They can also cause the generation of free radicals. When nanomaterials reach the land, they may contaminate the soil and spread to groundwater and surface waters.

Costly: For small businesses, the initial cost is expensive because of the specialized manufacturing systems and research and development needed to engineer nanoproducts.

Scalability: Only laboratory-scale production of a wide range of nanomaterials is currently possible. Techniques for scalable, regulated synthesis with dependable characteristics need to advance.

Regulations: Commercialization is hampered by regulatory uncertainties brought on by a lack of standardized safety data and rules tailored to unique nanotechnology. Harmonizing regulations internationally would be beneficial.

Lack of awareness: Farmers still have a poor understanding of nanotechnology. It is necessary to communicate costs and benefits for various applications in an effective manner.

Lack of skills: Multidisciplinary knowledge spanning fields like food technology, agriculture, and nanoscience is scarce. Building capacity is necessary.

Conclusions

Applications of nanotechnology in agriculture have enormous potential to enhance the environ-

ment and boost crop plant yield and quality. We provide an overview of recent studies on nanotechnology applied to agricultural production in this review, including nanosensors, nanobiotechnology, nanopesticides, nanomaterials that improve plant growth, seed germination, and stress tolerance, and nanofertilizers. Although nanotechnology has numerous advantages, there are still a lot of differences between agricultural production and laboratory research. A cost-effective way to use nanomaterials that strikes a balance between environmental preservation and agricultural productivity should also be identified. Nanotechnology has the potential to transform agriculture through the development of smart sensors, climate-resilient crops, nanopesticides, and nanofertilizers. However, to guarantee that the advantages are maximized while lowering any potential concerns, its implementation must be supported by rigorous consideration of safety, regulation, and equity. With more study and development, nanotechnology may be essential to providing a sustainable diet for the world's expanding population.

Buzzing towards a Greener Future: Black Soldier Flies in Organic Waste Management

Shanmugapriya V. and S. Karthikeyan

Introduction

Every year, millions of tonnes of food waste end up in landfills, contributing to greenhouse gas emissions and environmental degradation. With rapid urbanization and population growth, India generates over 68 million tonnes of municipal solid waste annually, with organic waste forming a significant portion. While traditional waste management methods struggle to keep up, nature has already provided a sustainable solution: the Black Soldier Fly (BSF). A remarkable insect that can transform food waste into a valuable protein source for livestock and aquaculture, making it an eco-friendly answer to two major global challenges waste management and food security (Surendra *et al.*, 2020; Lopes *et al.*, 2024). BSF larvae contain 42% protein and 35% fat, making them a viable alternative to conventional feed sources like fishmeal and soybean meal (Hale, 1973; Tepper *et al.*, 2024). Additionally, the larval frass serves as a nutrient-rich organic fertilizer, supporting sustainable agricultural practices (Lopes *et al.*, 2024). This paper highlights global advances, policy opportunities, and strategic steps to main-stream insect-based innovations into Indian agriculture. By integrating BSF systems into

urban and rural waste management frameworks, societies can achieve sustainable waste reduction, enhance food security, and promote environmental resilience.

Black Soldier Fly – A key species in bioconversion

The Black Soldier Fly (*Hermetia illucens*) is a species originating from South America and has gained worldwide recognition for its ability to efficiently decompose organic waste. Unlike houseflies, BSF does not spread diseases, making it a safer alternative for waste processing. The larvae of this insect are particularly remarkable, as they can break down various organic materials and convert them into high-protein biomass suitable for animal feed. BSF larvae have a short lifecycle of approximately 45 days, progressing through the stages of egg, larva, pre-pupa, and adult (Fig. 1).

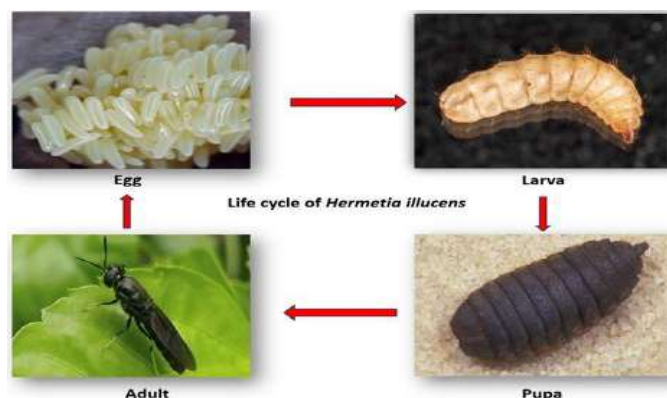


Fig. 1: Life cycle of *Hermetia illucens*

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The pre-pupal stage offers the highest nutritional value, making it the best phase for harvesting larvae for feed production. The species is now distributed globally, with extensive studies proving its potential as a sustainable alternative to conventional waste disposal and feed production systems.

Why is the BSF Important?

Tackling Food Waste: Globally, over 900 million tonnes of food waste are generated annually. BSF larvae can consume vast amounts of organic waste, diverting it from landfills and reducing methane emissions.

Sustainable Protein Source: BSF larvae are rich in protein (42%) and fat (35%), making them an excellent alternative to conventional protein sources like fishmeal and soybean meal.

Economic Benefits: BSF farming is cost-effective and can generate additional income for farmers by providing protein-rich feed and organic fertilizer.

Environmental Impact: The larval frass (waste residue) serves as a potent organic fertilizer, promoting sustainable agricultural practices.

Health and Hygiene: Unlike houseflies, BSF larvae do not spread diseases. Additionally, they can outcompete housefly larvae, reducing their population in waste areas.

Industrial Potential: Researchers are exploring the potential of BSF for producing biofuels, pharmaceuticals, and industrial enzymes.

Sustainable Insect Biomass Production

BSF farming is simple and scalable, making it accessible to farmers, waste management compa-

nies and even urban households. In mass culturing, adult flies are reared in controlled conditions where females lay eggs on cardboard or wooden strips near waste. The hatched larvae are transferred to shallow bins filled with organic matter, where they rapidly grow by consuming the waste. Within 10-14 days, the mature larvae can be harvested and used as protein-rich feed for poultry, fish, and even pets, while the leftover residue serves as a rich organic compost.

Waste Collection & Preparation: Organic waste such as vegetable scraps, fruit peels, and food leftovers is collected. Waste is shredded and pre-treated to enhance its nutritional availability for the larvae. The waste undergoes anaerobic digestion, which reduces pathogens and improves the nutrient profile for larvae consumption.

Larvae Rearing: BSF eggs are placed in a controlled environment (28-30°C, 60% humidity) for hatching. Hatched larvae are fed organic waste, growing rapidly over two weeks. The larvae are kept in aerated containers to ensure optimal growth conditions. Feeding adjustments are made every two days to provide a fresh, nutrient-rich diet.

Harvesting & Processing: Larvae are harvested at the pre-pupal stage when their nutritional content is at its peak. Harvested larvae are processed into dried meal, protein powder, or feed pellets. The frass is collected and used as an organic fertilizer.

Applications of BSF Farming

Animal Feed Production: The larval meal is an excellent protein source for poultry, fish and live-

stock. The larvae's high amino acid content ensures superior feed quality for animal growth and health.

Waste Management and Circular Economy:

Reducing food waste while creating valuable by-products fosters a sustainable economy. Municipal waste processing centers can integrate BSF farms to enhance waste reduction efforts.

Organic Fertilizer for Agriculture: The frass left behind by BSF larvae enriches soil and improves crop yield naturally. Farmers using BSF frass experience higher soil fertility and better moisture retention in the soil.

Bio-Manufacturing and Industrial Use: BSF is being explored for biofuel production, where larval fat is processed into biodiesel. Enzyme extraction from BSF can be used in pharmaceutical and biochemical industries.

Challenges and Solutions in BSF Farming

Challenges	Solution
Waste Segregation Issues: Contaminants like plastics and chemicals can harm the larvae.	Implement better waste sorting practices at the collection stage.
Scalability and Cost: Setting up large-scale BSF farms requires investment in infrastructure.	Government support, funding, and private sector collaborations can enhance scalability.
Market Acceptance: Consumers and industries need awareness about the benefits of BSF-derived products	Conduct awareness campaigns, research trials, and policy advocacy

The Future of BSF: A Game Changer for Sustainability

The integration of BSF-based bioconversion systems in urban waste management and agricultural practices is gaining momentum worldwide. Countries like India, the U.S., and China are investing in large-scale BSF farms to reduce food

waste and improve food security. By adopting BSF farming, industries and households alike can contribute to a greener, more sustainable future. Commercially, BSF farming offers multiple revenue streams such as, i) dried larvae can be sold as high-protein feed for poultry, fish, and pet industries; ii) BSF oil, extracted from the larvae, is used in animal feed and biofuel production; iii) Frass (larval waste) serves as an organic fertilizer with excellent soil-enhancing properties; iv) Egg and larval starter kits are in high demand among small-scale farmers.

Expected Impact of BSF Farming Expansion

Reduction of Greenhouse Gas Emissions: Diverting organic waste from landfills will lower methane emissions, significantly reducing the carbon footprint.

Sustainable Livestock Feed Industry: BSF protein production could replace environmentally harmful fishmeal industries, promoting ocean conservation.

Enhanced Waste Management Efficiency: Cities that integrate BSF-based systems can reduce landfill dependency and waste disposal costs.

Job Creation and Economic Growth: BSF farming can generate employment opportunities in waste processing, feed production, and research sectors.

Conclusion

The Black Soldier Fly is revolutionizing organic waste management by providing a zero-waste solution that benefits the environment, farmers, and the economy. With its ability to convert waste into protein-rich feed and organic fertilizer, this insect holds the potential to transform waste

Indian Government Initiatives Supporting BSF Farming

Initiative	Level	Description	Impact
ICAR-CIBA MoU	National	Explores BSF meal for aquafeed	Promotes sustainable aquaculture
Gobardhan Yojana	National	Likely supports BSF through waste-to-wealth programs	Enhances organic waste processing
National Mission on Sustainable Agriculture	National	Indirectly promotes BSF via sustainable agriculture	Supports eco-friendly farming practices
IPAR, Nagaland	State	Funds startups like “Waste to Protein” for BSF-based waste processing	Reduces landfill waste, creates economic opportunities
Kochi Corporation	Local	BSF units process 8,000 tonnes of waste in six months	Cost-effective waste management, environmental benefits
Manguluru Swachh Initiative	Local	BSF compost unit for household waste	Scalable model for urban waste management

management and sustainable agriculture on a global scale. Investing in BSF farming is not just an innovative approach it is a necessity for a sustainable future.

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Is “Spring Maize” a Boon or Bane in Scenario of Punjab?

Sandeep Singh

With around 70% of the population living in rural areas and depending on agriculture and animal husbandry for their livelihood, India is an agricultural nation. With a contribution of roughly 4.9% of the nation's GDP, livestock farming is regarded as one of the pillars of the rural economy and a significant subsector of Indian agriculture (Anonymous, 2020). The primary obstacle to the nation's dairy industry, which has placed a strong emphasis on green fodder conservation, is the lack of green fodder during the lean period.

As of right now, the cattle industry accounts for 25.70 percent of India's agricultural GDP (Anonymous 2017a) and 36.01 percent in State of Punjab (Anonymous 2017b). Even though India is the world's top producer of milk, the dairy industry has numerous challenges, including low animal productivity and a lack of high-quality green fodder and fodder seeds. The availability of concentrates, dry fodder, and green fodder is severely lacking throughout the nation. According to Anonymous (2012), there is now a 35% shortage of green fodder.

Making silage is a popular idea in dairy states like Punjab, where it has been utilized to feed animals during times of famine (Brar *et al*, 2019). When grasses or other fodder crops (such sorghum and forage corn) with a high enough moisture content and soluble carbohydrate content are kept in anaero-

bic conditions in a structure called a silo, silage is the end product. The feed goes through an acid fermentation process during ensilage, where bacteria convert the raw material's carbohydrates into lactic, acetic, and butyric acids. As a result, the pH is lowered, inhibiting the growth of spoilage micro-organisms, most of which cannot withstand acidic environments (Singh and Neelakantan, 2007).

On the other side, there are some major constraints related to silage production. It is already promoted that there is need change the crop-cycle (Wheat-rice) in Punjab as rice consume a large amount of water. So, maize crop is suggested as alternative for rice. Rice variety “Pusa 44” is widely grown in Punjab and Haryana due to its high yield of 35-37 quintals per acre (0.4 ha) but takes 155-160 days to mature. As a long-duration variety, Pusa 44 is harvested towards the end of October or early November, leaving little time for preparing the fields for sowing the Rabi (winter) wheat crop. This leads farmers to burn the standing stubble after harvesting paddy, which contributes to air pollution in Delhi-National Capital Region and other parts of North India. Additionally, due to long duration, it need more number of irrigations as well. Short- to medium-duration paddy varieties like PR124, PR126, PR131 and PR (developed by Punjab Agricultural University or PAU), along with the more

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recent Pusa-2090 (developed by the Indian Agricultural Research Institute), are seen as viable alternatives to Pusa 44. In contrast, short-duration varieties take fewer days to mature. For instance, PR126 and PR131 take 93 and 110 days, respectively and can be harvested well before the wheat sowing season. But according to a report of “The Indian express”, Punjab has found that maize is both, a blessing and a curse in state that is struggling with groundwater depletion.

Parallel to the paddy harvest, the crop is sown in two distinct seasons: the water-intensive spring/summer season (February to June) and the more water-conservative *kharif* season (June to October). This creates a growing conundrum regarding how to strike a balance between the advantages of this crop and the urgent need to preserve water resources. As per the initial reports from private companies that sell maize seeds in Punjab and officials from Punjab Agricultural University (PAU), the area planted to spring maize has grown to 1.80-1.90 lakh hectares this year, up from approximately 30,000 to 35,000 hectares ten years ago and 1.50 lakh hectares last year. Although the Punjab Revenue Department does not formally track spring maize sowing because it is not regarded as a part of the principal *kharif* crop cycle, this represents an exponential expansion in the area under spring/summer maize during a ten-year period. This season, the state sold between 3,500 and 3,800 metric tons of spring maize seeds. Since one acre requires eight kg of seeds, Punjab has planted between 4.50

and 5 lakh acres of maize. The low groundwater table in Punjab is severely impacted by the 5-19 irrigations that spring maize requires, depending on the type of soil and irrigation techniques. Likely, spring maize crops, the short-duration paddy cultivars require 20 to 21 irrigations. Apart from this, consumption of more fertilizers also a concern which effect the soil properties. Good supply of nitrogen to plants promotes faster photosynthesis by increasing capture of sunlight by the crops and the efficiency of conversion to biomass, thus improving biomass production. Photosynthesis activity is associated with nitrogen content in leaves. The amount of dry matter of silage maize increases with the level of nitrogen in the leaves (Wysokinski *et al*, 2024).

Reviews of Farmers and Scientists

Amritpal Singh Randhawa, who grows spring maize on 42 acres at Phuglana village in Hoshiarpur district, said, “If maize is sown in the first fortnight of February, when the weather is cooler, it consumes less water. Our soil is moist and has a heavy texture due to water retention, and we need only five irrigations until the end of June. After that, I do not grow paddy but cultivate vegetables. This way, I save water. However, when farmers sow maize in sandy or light-textured soils, it requires multiple irrigation cycles. And, if they then go for paddy, it puts a huge strain on groundwater. Thus, the water consumption by maize depends on several factors.” Sukhvinder Singh, a farmer from Barnala district in Punjab, switched to PR126 a few years ago. Around 2020, he also began sowing spring

maize on 1.2 hectares (ha) of his 20 ha farm as a summer crop. “Now we have more time to sow paddy, so after harvesting wheat, we plant maize for silage (fodder) for cattle and harvest it before the paddy season starts,” he said. Maize sown in March and April is even more water-intensive than paddy, as these are dry months and the crop needs at least 18-20 irrigation cycles due to high evaporation rates. “Up to 90 days after sowing, the crop needs irrigation every second day,” explained Sukhvinder.

However, PAU has recommended sowing the crop between January 20 and February 15 as crop sown after mid-February may experience high-temperature stress and require more water. “Spring maize is another paddy (in terms of depleting groundwater). The right season for maize is *Kharif* (from June onwards),” said Dhanwinder Singh, principal soil chemist at PAU’s soil science department. In fact, maize has long been one of the crops recommended by the governments of Punjab and Haryana to diversify the rice-wheat cropping system. However, the growing trend of spring maize is becoming a serious concern for Punjab’s falling groundwater levels.

***Kharif* maize: a much needed alternative**

On the other hand, the Punjab government actively supports *kharif* maize, which is grown alongside paddy during the monsoon season and harvested in late October to November. It is thought to be a great substitute for water-intensive paddy. *Kharif* maize is one of the greatest crops to lessen Punjab's reliance on groundwater because it requires

only three to four irrigations during the season and is less water-intensive due to the monsoon season. Notwithstanding its potential, the area planted to *kharif* maize has decreased recently, falling from 1.05 lakh hectares to 1.30 lakh hectares over a ten-year period to only about 80,000 hectares in 2024. This is significantly less than the 5.5 lakh hectares of maize that experts, including PAU scientists, have recommended as part of the state's crop diversification strategy.

Production cost of silage maize is little bit more as other crops

In order to investigate the costs associated with processing green fodder and the different justifications for processing, the study was carried out by Harparteet *et al.* (2018), in three agroclimatic zones of Punjab state between 2017 and 2017. It has been shown that the farmers who process green Fodder was making silage from three crops: sorghum, bajra, and maize. Sorghum (Rs 30.98 q⁻¹), bajra (Rs 30.07 q⁻¹) and maize (Rs 31.50 q⁻¹) had the highest overall cost of silage production. The primary motivation for processing green fodder was to guarantee a consistent supply of feed, which was followed by ensuring that fodder was available at consistent prices. Since animals prefer preserved food, preserved fodder is more nourishing and a lack of land for the production of feed. The labor costs are reduced and the variable cost of milk production is decreased when feed is processed into silage. As a result, farmers ought to be urged to turn their excess green feed into silage.

Other sources can be used for feed/ silage

Bajra and Sorghum are good alternative to maize for silage production as these are drought and heat tolerant crops but produce low energy as compare to maize. Alfalfa, has high protein content, ideal for dairy cows, excellent for soil health due to nitrogen fixation but needs proper wilting and fermentation management to avoid spoilage due to its buffering capacity. Mulberry leaves are used to feed livestock during lean times and are a great source of crude protein (20-24%). In order to raise silage's CP content. The use of mulberry leaves as silage without the addition of additives like molasses was recommended by (Ba *et al.*, 2005). According to Luby (2003), the apple (*Malus domestica* Borkh.) is a climacteric fruit that is grown in temperate regions of the world and produces 75.9 million tonnes annually (FAO, 2019). Apple pomace, an industrial waste and environmental pollution, is the residue that remains after the juice from apple fruit is extracted. Apple pomace has long been used as an ingredient in animal feed. Fresh apple pomace must be either ensiled or dehydrated for extended preservation since its high moisture and fermentable sugar content cause it to degrade quickly (Shalini *et al.*, 2010; Crawshaw, 2004). Fresh apple pomace can be used as an alternative animal feed resource in heifer rations because it has an average CP content of 4.5% (Chandel *et al.*, 2015).

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Successful Biological Control Projects: Analysis, Trends and Future Possibilities of Biological Control

Sharvari Dinesh Saharkar and Mahesh Pathak

Abstract

Successful Biological control helps manage invasive pests and weeds demonstrates its effectiveness as a sustainable, eco-friendly and economically viable pest management strategy. Rachel Carson's *Silent Spring* (1962) was instrumental in raising awareness of pesticides hazards, reigniting interest in biological control as an eco-friendly alternative. Unlike chemical methods biological control provides a long-term, self-sustaining solution that minimizes harm to non-target species and eco-systems. It encompasses three key strategies: conservation (preserving natural enemies), augmentation (boosting their populations through releases), and classical control (introducing natural enemies to manage invasive pests). These approaches collectively contribute to integrated pest management (IPM), reducing reliance on chemical pesticides.

Introduction

Biological control the natural regulation of pests by predators, parasites, and pathogens is a vital yet often overlooked component of sustainable agriculture. While these natural processes occur continuously, human intervention can enhance their effectiveness. However, the widespread use of chemical insecticides after World War II disrupted ecological balance, harming beneficial organisms and leading to pesticide resistance. The decline of natural enemies allowed pest populations to rebound, creating a cycle of increased chemical dependency and environmental degradation. Despite its effectiveness, biological control faces skepticism due to misconceptions about its reliability and speed. However, numerous success stories worldwide demonstrate its potential.

For example, in India, biological control has been successfully used against pests like the sugarcane woolly aphid and the papaya mealybug, reducing pesticide dependence and promoting agricultural sustainability. This highlights successful case studies from India, showcasing the practical benefits of biological control. By examining these real-world applications, it aims to inform, educate, and inspire future generations to adopt eco-friendly pest management strategies. Embracing biological control is crucial for building a more resilient and environmentally sustainable agricultural system.

Successful Biological Control projects

Biological Control of the Rugose Spiralling Whitefly (*Aleurodicus rugioperculatus*)

Pest Introduction and Spread: *Aleurodicus rugioperculatus* (RSW) identified as an invasive pest

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in Tamil Nadu, Andhra Pradesh, and Kerala. Infested coconut, banana, custard apple and ornamental plants.

Natural Enemy and Biological Control Strategy:

Several natural enemies were recorded attacking RSW. Maximum parasitism observed by *Encarsia guadeloupae* (Viggiani). *E. guadeloupae* was fortuitously introduced from Lakshadweep islands in the 1990s.

Implementation Strategy: Conservation biological control approach adopted. Farmers were advised to follow a non-chemical pest management strategy.

Outcome: Increased *E. guadeloupae* population led to effective suppression of RSW in most areas (Selvaraj et al., 2017).

Biological Control of Cottony Cushion Scale (*Icerya purchasi*)

Origin and Introduction: *Icerya purchasi* originated in Australia. It likely entered India through imported orchard stock or flowering plants from Sri Lanka.

First Report and Spread: First recorded in 1928 in the Nilgiris, Tamil Nadu, on *Acacia decurrens* and other *Acacia* species. Later spread to Karnataka, Kerala, and Maharashtra. Infested 117 host plants, posing a major threat to fruit crops, particularly citrus.

Challenges in Control: Chemical control methods proved completely ineffective.

Introduction of Biological Control Agent: *Rodolia cardinalis*, a coccinellid predator native to Australia, was introduced to India. Initially imported in 1926

via the USA and South Africa, and again in 1930 via Egypt.

Implementation and Success: From 1930, *Rodolia cardinalis* was released in:

- ✓ The Nilgiris and upper Palni Hills (Tamil Nadu).
- ✓ Infested regions of Maharashtra, Karnataka, and Kerala.

The predator provided significant control of *Icerya purchasi*, making this a successful case of classical biological control.

Biological Control of the Fall Armyworm (*Spodoptera frugiperda*)

Invasive Pest Status and Spread: Originally spread across sub-Saharan Africa before entering South Asia. First reported in India by ICAR-NBAIR (July 2018) as a PEST ALERT. Initial damage was noticed in Karnataka, with incidence rates between 9.0-62.5%. By August 2019, FAW was reported in almost all Indian states except J&K and Himachal Pradesh.

Search for Indigenous Natural Enemies: A complex of native parasitoids and predators was identified, including:

- ✓ **Egg parasitoids:** *Telenomus* sp. and *Trichogramma* sp.
- ✓ **Egg-larval parasitoid:** *Chelonus* sp.
- ✓ **Gregarious larval parasitoid:** *Glyptapanteles creatonoti*
- ✓ **Solitary larval parasitoid:** *Campoletis chloridae*
- ✓ **Larval-pupal parasitoids:** *Ichneumonid* sp. and *Trichomalopsis* sp.

✓ **Predators:** *Forficula* sp. (earwig), *Andrallus spinidens* and *Eocanthecona furcellata* (predatory bugs).

Natural Pathogens and Bioagents Identified:

Entomopathogenic fungi: *Metarhizium rileyi* (caused significant FAW larval mortality in Karnataka). Viral infections in FAW larvae were also recorded.

Evaluation and Development of Biocontrol Agents by ICAR-NBAIR:

Intensive lab testing and small plot trials led to the identification of effective bioagents for Integrated Pest Management (IPM):

- ✓ **Egg parasitoids:** *Trichogramma chilonis*, *Trichogramma pretiosum*, *Telenomus remus*.
- ✓ **Microbials:** *Metarhizium anisopliae* (NBAIR Ma-35), *Beauveria bassiana* (Bb-45), *Bacillus thuringiensis* (NBAIR Bt-25).
- ✓ **Entomopathogenic nematodes (EPNs):** NBAII Hi-38 and NBAII Hi-101.

Field Trials and Farmer Adoption: Bioagents are widely tested and validated across different states through: Farmer field trials, AICRP Biocontrol centres, Krishi Vigyan Kendres (KVKs). Highly promising results have encouraged further adoption by researchers and farmers (Ballal et al., 2021a, b).

Analysis of Successful Biological Control Projects

Target-Specific Approach: Each project involved identifying and introducing highly effective natural enemies, such as *Dactylopius ceylonicus* for prickly pear, *Rodolia cardinalis* for cottony cushion scale, and *Acerophagus papayae* for papaya mealybug.

Integration of Indigenous and Exotic Agents: In

cases like Eucalyptus gall wasp and fall armyworm, a combination of imported parasitoids and indigenous natural enemies played a crucial role in pest suppression.

Economic and Environmental Impact: Projects like the cassava mealybug and papaya mealybug control resulted in significant financial savings for farmers while reducing pesticide use, minimizing environmental hazards.

Conservation and Fortuitous Introduction: The success of rugose spiralling whitefly and sugarcane woolly aphid management relied on conserving existing natural enemies rather than introducing new ones.

Trends in Successful Biological Control Projects

The analysis of various biological control initiatives reveals several emerging trends that contribute to their success:

Increased Use of Classical Biological Control:

Many successful projects, such as those for prickly pear, cottony cushion scale, and cassava mealybug, relied on the introduction of natural enemies from the pest's native range, ensuring long-term suppression.

Integration of Indigenous and Exotic Agents:

A shift towards utilizing both imported and native natural enemies, as seen in the Eucalyptus gall wasp and fall armyworm control efforts, enhances adaptability and sustainability.

Focus on Conservation Strategies: Emphasis on preserving existing natural enemy populations, such as for sugarcane woolly aphid and rugose spiralling whitefly, reflects a growing trend toward non-chemi-

cal, habitat-based pest management.

Future Possibilities in Successful Biological Control Projects

Research Priorities

- ✓ Investigate the exact mechanisms by which natural enemies control pests in their environment.
- ✓ Identify factors contributing to the success or failure of biological control agents in specific conditions.
- ✓ Study how climate change affects pests, their natural enemies, and their interactions.
- ✓ Explore the interactions between transgenic crops and biocontrol agents.

Popularizing Biological Control: Control provides a long-term, self-sustaining solution that minimizes harm to non-target species and ecosystems. It encompasses three key strategies: conservation (preserving natural enemies), augmentation (boosting their populations through releases), and classical control (introducing natural enemies to manage invasive pests). These approaches collectively contribute to integrated pest management (IPM), reducing reliance on chemical pesticides.

Conclusion

The success of biological control projects worldwide, particularly in India, highlights its immense potential as a sustainable pest management strategy. By leveraging natural enemies such as predators, parasitoids, and pathogens, farmers have effectively suppressed pests while reducing reliance on chemical pesticides. These projects have not only

minimized environmental damage but also contributed to increased crop yields, economic savings, and improved soil and ecosystem health. Case studies, such as the control of the papaya mealybug using parasitoid wasps and the management of sugarcane woolly aphids through predator releases, demonstrate the viability of biological control in diverse agricultural settings.

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Unpacking Food Price Inflation: Understanding the Economic Forces behind Rising Meat Cost

Lovi H. Chophi and Kanzam Shubhrata Singha

The increasing cost of everyday meals is a growing concern for consumer and producers. This article examines the multifaceted economic factors that contribute to the increasing agricultural input prices, transportation and fuel expenses, inefficient supply chains, climate change, market intermediaries, changing consumer demands, and government policies collectively impact food prices. By unpacking these interconnected elements, the article provides clearer understanding of food inflation and suggests practical steps to create more stable and affordable food economy.

What makes our meal more expensive?

Have you noticed how your regular grocery list now costs more than it did just a few months ago? Whether it's the price of vegetables, cooking oil, or packaged snacks, the cost of our daily meals seems to be rising steadily. But what exactly is making our food more expensive?

Rising food costs affect everyone from households struggling to manage budgets to farmers trying to earn fair prices. Behind every price tag in the market lies a chain of processes, decisions, and challenges that influence what we pay for our meals. In this article, we take a closer look at the economic forces that make our meals more expensive.

Agriculture input cost are rising

One of the biggest contributors to food price inflation is the increasing cost of inputs like seeds, fertilizers, pesticides, and irrigation. Farmers rely heavily on these essentials to produce good yields. When international prices of fuel or fertilizers rise, it directly affects the cost of production. For example, a spike in the price of urea or diesel increases the overall expense of cultivation. This leads farmers to raise their selling prices to maintain profits making food more expensive for consumers.

Transportation and Fuel Prices

Transporting food from rural farms to urban markets involves trucks, storage units, and distribution networks. The rising cost of petrol and diesel plays a major role in inflating food prices. When transportation becomes more expensive, the additional cost is passed along the supply chain and ultimately reaches the consumer. Perishable items like fruits and vegetables require faster delivery and cold storage, both of which need energy and investment further pushing up prices.

Post-Harvest Loss and Inefficient Supply Chains

India loses a significant amount of food post-harvest due to lack of proper storage, packaging, and market access. In the case of perishable goods like tomatoes or mangoes, even a few days of delay can lead to spoilage and wastage. To recover from these

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losses, traders increase prices during low-supply periods. This inefficiency in the supply chain from farm to fork adds to the hidden costs of our meals.

Climate Change and Weather Uncertainty

Erratic weather patterns are becoming more frequent due to climate change. Droughts, unseasonal rain, and floods damage crops, reduce yields, and disrupt harvest timings. Unpredictable weather not only reduces supply but also increases the risk for farmers, who may then grow less or shift to other crops. Reduced availability means higher prices, especially for essentials like grains, vegetables, and pulses.

Middlemen and Market Dynamics

Many agricultural markets in India still rely on middlemen or commission agents who buy produce from farmers and sell to wholesalers or retailers. Often, a significant portion of the consumer price goes to these intermediaries, not to the farmers. These middlemen can influence prices by hoarding, delaying supply, or charging commissions factors that increase food prices without necessarily improving quality or quantity.

Changing Consumption Patterns

As incomes rise, urban consumers are demanding more processed foods, imported ingredients and packaged meals. This shift in demand changes the type of food being grown, and processed food production involves packaging, branding, and advertising all of which cost money. The end result is a meal that is more expensive not just because of ingredients, but due to the entire production and

marketing process.

Government Policies and Global Trends

Subsidies, import-export bans, GST rates, and international market fluctuations also play a role in price changes. For instance, if a global shortage affects wheat or oil prices, Indian markets feel the impact too. Government interventions can help stabilize or worsen prices depending on how and when they are implemented. Economic policies affect farmers, traders, and consumers alike.

Conclusion

What makes our meals more expensive is not just one factor it's a combination of rising input costs, inefficient systems, unpredictable weather, global markets, and shifting consumer demands. Understanding these factors helps us see that food pricing is not random, but the result of many interconnected elements. As a society, investing in better storage, efficient transport, direct farmer-to-market models, and climate-resilient agriculture can help reduce these pressures. Only then can we make our meals more affordable, while ensuring fair returns to the farmers who feed the nation.

Improving Rice Cultivation using CRISPR-Cas9 Mediated Genome Editing Technology

Gouri Thengal

Abstract

A new era of precision agriculture has begun with the development of CRISPR-Cas9 technology, which makes targeted genome editing possible with previously unheard-of accuracy and efficiency. To boost productivity, nutritional value, and tolerance to biotic and abiotic stressors, CRISPR-Cas9 is being used in rice (*Oryza sativa*), one of the most significant staple crops in the world. The revolutionary influence of CRISPR-Cas9 on rice enhancement is examined in this article, along with its uses, most recent developments, and possible future paths.

Introduction

Rice is essential to global food security since it provides food for more than half of the world's population. On the other hand, conventional breeding techniques are laborious and frequently constrained by the gene pool's capacity to produce desired features. Genetic engineering, and specifically CRISPR-Cas9 (Clustered Regularly Interspaced Short Palindromic Repeats associated protein 9), has made it possible for scientists to swiftly, accurately, and economically change genomes. New promise for the sustainable intensification of rice production is provided by this gene-editing method, which is currently at the forefront of agricultural research.

Application of CRISPR-Cas9 in Rice Genome Editing

Increasing Grain Quality and Yield: In order to create more productive cultivars, researchers have employed CRISPR-Cas9 to target genes linked to

yield, including as GW2 (grain weight), GS3 (grain size), and Gn1a (grain number). Field tests have shown that changes to these genes have real advantages, and they may be able to help feed the world's expanding population.

Increasing Nutritious Quality: Increasing Nutritious Quality Iron, zinc, and vitamins are among the vital minerals that can be added to rice by biofortification using CRISPR-Cas9. Because CRISPR cuts are non-transgenic, researchers have been able to precisely and widely adopt rice lines with higher vitamin A content, akin to Golden Rice, by editing genes linked to nutrition metabolism.

Developing Disease and pest Resistance: Increasing Resistance to Pests and Diseases. In order to fight off diseases like blast fungus (*Magnaporthe oryzae*) and bacterial blight (*Xanthomonas oryzae*), rice has been treated with CRISPR to either activate resistance genes or block susceptibility genes.

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Because of this, fewer chemical pesticides are required, encouraging more ecologically friendly farming methods.

Adaptability to Abiotic Stresses: CRISPR-Cas9 has been used to alter stress-related genes including DREB and OsNAC, boosting the plant's resistance to harsh environments as a result of climate change's increased frequency of droughts, floods, and salinity. These modifications aid in preserving yields in harsh environmental conditions

Increasing Breeding Cycle Speed: Since CRISPR-Cas9 allows for precise and direct genetic alterations, it speeds up the breeding process in contrast to traditional breeding, which can take years to create new types. This speeds up the creation of better rice strains, enabling prompt adaptation to new problems.

Recently released Genome Editing Rice Varieties through CRISPR-Cas9

India recently made a major breakthrough in agricultural biotechnology by introducing its first genome-edited rice varieties created with CRISPR-Cas9. Enhancing production, promoting sustainable farming methods, and improving climate resistance are the goals of these cultivars.

DRR Dhan 100 (Kamala): Developed by ICAR-Indian Institute of Rice Research (IIRR), Hyderabad
Parent Variety: Samba Mahsuri (BPT-5204).

Genome Editing Target: CKX2 (Cytokinin Oxidase 2) gene, also known as Gn1a.

Pusa DST Rice 1: Developed by ICAR-Indian Agricultural Research Institute (IARI), New Delhi.
Parent Variety: MTU1010 (Cottondora Sannalu)

Genome Editing Target: DST (Drought and Salt Tolerance) gen.

Conclusion

The field of rice genetics is changing due to CRISPR-Cas9 technology, which provides a potent way to address the dual issues of environmental sustainability and global food security. The use of CRISPR-edited rice cultivars may become common place in agriculture as legal frameworks change and public acceptance increases. The key to maximizing the potential of this ground-breaking technology will be sustained investment in research, open communication and careful application. The precision of molecular biology, rather than chemicals or machinery, could be the driving force behind a second Green Revolution in the years to come, thanks to CRISPR-Cas9.

The Future of Farming: How Artificial Intelligence is Revolutionizing Agriculture

Indrani Borgohain

Abstract

Agriculture has faced several problems presented by population growth and climate change, and innovative and new technologies are needed to maintain and increase agricultural productivity. One such example of change that presents potential answers in a variety of agricultural production domains is Artificial Intelligence (AI). Precision farming, robotic automation, machine learning applications, sensors are some of the technologies developed to mitigate problems related to agriculture. It demonstrates how agricultural integration has made AI a great tool for crop management decision-making, offering predictive analytics and real-time monitoring and provide higher agriculture output and resilience.

Introduction

The world's population is predicted to have grown to 10 billion people by 2050, putting agriculture under unprecedented pressure to boost output in a sustainable manner. Climate change, water scarcity, environmental deterioration, and reliance on traditional energy sources are some of the major issues faced by agriculture. With the additional problems of various environmental problems, there is an urgent need for novel solutions to increase farm productivity and efficiency. A global shift in agriculture is required to move from traditional to modern automated methods to meet the rising demand. The introduction of artificial intelligence (AI) has caused a significant shift in technological advancement in every industrial sector worldwide. Through the production of food, agriculture uses

natural resources to support the world's population and conversely AI is closely linked to automated systems, complex communications, modeling, and decision-making methodology. Although AI inevitably appears to be a distinct field from agriculture, but introduction of AI-powered agriculture such as robotics, drones, and sensors has the potential to revolutionize the sector and increase sustainability and efficiency. AI-powered farming solutions give farmers a faster go-to-market (GTM) strategy for crops, increase crop quality, and increase productivity while using fewer resources. AI integration in agriculture presents a wealth of opportunities for improved environmental sustainability, waste reduction, and resource use. Therefore, evaluating the use of AI in agriculture with respect to crop, soil, disease, and pest control is essential to meet the

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current needs of the rising population and for attaining sustainability.

AI in Agriculture

AI is changing the face of agriculture from environmental effect forecasts to efficient resource use and crop management.

Precision Agriculture: Precision farming is a prominent AI application that offers improved accuracy and control over agricultural practices. GPS and IoT devices have been used to capture extensive data in agricultural settings for precision farming. This dataset is used to get the temperature and crop health, fertilizer availability, and soil moisture content. AI systems analyse crop data and make recommendations for farmers on sowing, irrigation, and harvesting.

Agricultural Robotics: Agricultural robots improves operational efficiency, decreases the need for human resource components, and automates labour-intensive tasks. AI-capable robots are being used for several tasks, including weeding and seed harvesting. These autonomous devices can work around the clock in a variety of weather conditions and carry out field navigation with a high degree of accuracy. In addition to expediting agricultural procedures, robotics reduces human error and raises the general criteria for agricultural output quality.

Sensors: In this technological transformation, sensors are essential. It can be defined as a device that diffuses an impulse for measurement or control operation and counters a physical stimulus such as heat, light, sound, pressure, magnetism, or a specific

motion. To put it another way, it is a smart gadget that recognizes motion, heat, and light in the environment and transforms the information into an analog or digital representation. By employing smart sensors in agriculture, farmers may anticipate disasters brought on by both biotic and abiotic variables, preserving resources and promoting sustainability, shielding crops from natural disasters, and ultimately boosting productivity.

Impact of artificial intelligence (AI) in agriculture

The core of farming is always about finding ways to produce more crops without compromising their quality. In order to meet difficult challenges like climate change, labour shortages, urbanization leading to a reduction in the amount of land available for farming, poor soil fertility of the available land, declining water resources, etc., productive farms make the best use of natural resources like soil, water, and air. They also allocate natural resources for the future. Hence, crop identification, crop type classification, and crop health grade evaluation should be essential components of any agricultural monitoring system. Therefore, Artificial Intelligence (AI) is now seen as a revolutionary development in the agricultural industry. Many agricultural operations are benefited from AI's ability to eliminate monotony and chores, and that time can be used to develop innovative AI solutions that surpass human skills. Soil health and productivity contribute to meeting climate and biodiversity targets, creating a clean and circular economy, reversing biodiversity loss, and protecting human health.

An artificial neural network (ANN) predicts the field capacity and soil moisture content. The AI technologies are beneficial for estimating biological parameters like soil enzyme activity, predicting soil fertility indicators and pH levels determination of various types of soil. Likewise, there are various techno-logies developed for various aspects of agriculture such as crop management, sowing, nutrient, water, weed, pest, disease management and harvesting is getting popular for its precision and accuracy.

Conclusion

The agricultural sector has been dealing with several challenges, such as weeding, plant monitoring, effective irrigation systems, and a labour shortage. Using modern technology for sustainable farming through effective resource use is still crucial to overcome all these obstacles. By improving proficiency, productivity and sustainability, artificial intelligence (AI) is revolutionizing the agricultural sector. By automating labour-intensive processes, it reduces input waste without sacrificing quality, enabling intelligent farming practices. Additionally, traditional farming is being transformed into a data-driven sector by AI-driven advancements like robotics, drones, and IoT-based sensors. Altogether, it can be said that AI has the ability to completely transform the agricultural sector by promoting a farming ecosystem that is more productive and sustainable.

Redgram Varieties Suitable for Tamil Nadu Cultivation

S. Ranjith Raja Ram and S. R. Venkatachalam

Introduction

Red gram, is a vital pulse crop in India, with a significant role in food security and soil fertility. It also known as pigeon pea, is believed to have originated in India. Some sources suggest that the crop was domesticated in the Indian subcontinent at least 3,500 years ago. While some researchers believe Africa to be the origin, the consensus points towards India as the primary center of origin. Red gram is a good source of protein and various nutrients like lysine, riboflavin, thiamine, niacin, and iron. In addition to being an important source of human food and animal feed, Red gram also plays an important role in sustaining soil fertility by improving physical properties of soil and fixing atmospheric nitrogen. In the 2024-25 season, the area under red gram cultivation in India was reported as 46.50 lakh hectares (114.90 lakh acres), a notable increase compared to the 40.74 lakh hectares (100.67 lakh acres) during the same period in 2023-24. Government estimates for the 2024-25 season project an all-India red gram production of 3.50 million tonnes. In India, major redgram producing states are Maharashtra (9.48 lakh tonnes), Karnataka (8.75 lakh tonnes), Uttar Pradesh (3.80 lakh tonnes), Gujarat (2.66 lakh tonnes) Jharkhand (2.12 lakh ton-

es) and Madhya Pradesh (1.72 lakh tonnes). The total cost of cultivating red gram varies, but a study in Marathwada region found the per-hectare cost to be around Rs. 33,341.27. Another study in Kalaburagi district of Karnataka found the total cost to be around Rs. 39,792.2 ha⁻¹ for small farms, Rs. 38,504 ha⁻¹ for medium farms, and Rs. 37,003.8 ha⁻¹ for large farms. ICPH 8, the world's first pigeonpea hybrid, was released jointly by ICRISAT and ICAR in 1991. The hybrid yields 25-30% more than pure line cultivars in farmers' fields. Moreover, it is drought-tolerant.

Varieties of Redgram

VBN (Rg) 3

- ✓ This variety is developed by hybridization followed by selection from VBN 1 x Gulberga.
- ✓ Short duration varieties (100-110 days)
- ✓ It yields up to 880 kg ha⁻¹ in rainfed.
- ✓ It offers tolerance to Sterility Mosaic Disease and has uniform maturity.
- ✓ Markazhipattam (Winter Irrigated): All district except the Nilgiris and Kanyakumari.
- ✓ Chithiraipattam (Summer Irrigated): All district except the Nilgiris and Kanyakumari wetland bunds.

APK 1

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- ✓ This variety is developed by pure line selection from ICPL 87101 suitable for Madurai, Ramnad, Virudhunagar and Sivagangai districts.
- ✓ Medium duration varieties (120-130 days)
- ✓ This can be grown as a sole crop in irrigated condition and as a intercrop in rainfed condition. It yields up to 870 kg ha⁻¹ in 105 days with drought tolerance and moderately tolerant to SMD. Its flower is dark red in colour and pods are long with bold seeds.
- ✓ Being a determinate type, special care should be taken to control the pod borers.
- ✓ Chithiraipattam (Summer Irrigated): All district except the Nilgiris and Kanyakumari wetland bunds.

Co 5

- ✓ This is a mutant from Co 1 (16 kR gamma rays).
- ✓ This variety is suited both for irrigated and rainfed conditions in all seasons.
- ✓ This can be grown in Kancheepuram, Tiruvallur, Dharmapuri, Erode, Coimbatore, Vellore and Tiruvannamalai districts during *kharif* and *rabi* seasons. During summer, it can be grown throughout Tamil Nadu except Nilgiris and Kanyakumari districts.
- ✓ Under irrigated conditions this variety yields upto 1500 kg ha⁻¹ and under rainfed condition, the crop yields up to 700-800 kg ha⁻¹.
- ✓ This variety is tolerant to root rot and pod fly damage.

Co (Rg) 7

This variety is developed by hybridization

followed by selection from PP 9825 x (ICP 8863 x AL 101) x (PA 128 x TT 6), suited for both irrigated and rainfed conditions.

- ✓ Average yield of the crop is 1020 kg ha⁻¹.
- ✓ At all India level the variety named as CoRG 9701 and recommended for cultivation in the states of Andhra Pradesh, Karnataka, Tamil Nadu and Orissa. The maximum yield recorded was 2800 kg ha⁻¹.
- ✓ 100 seed weight is 9-11.4 gm.
- ✓ It is a heavy branching type with more pod clusters and more number of pods branch⁻¹ which attributes its higher yield.
- ✓ This can be grown as *kharif* crop in all districts of Tamil Nadu and also grown as a summer crop where ever irrigation facilities available.
- ✓ Long duration varieties (180 days).
- ✓ Vaigasi pattam (May-June): Krishnagiri, Salem, Erode, Coimbatore, Dindigul, Theni and Madurai.
- ✓ Purattasipattam (September- October): Vellore, Thiruvannamalai, Dharmapuri, Erode, Salem, Namakkal, Coimbatore, Dindigul, Theni, Pudukkottai, Sivagangai, Perambalur and Ariyalur.
- ✓ Markazhipattam (Winter Irrigated): All district except the Nilgiris and Kanyakumari.
- ✓ Chithiraipattam (Summer Irrigated): All district except the Nilgiris and Kanyakumari wetland bunds.

Co 6

- ✓ This is a mutant variety from SA 1.

- ✓ Suited for all districts and can be grown as rainfed crop in *kharif* season.
- ✓ Tolerant to pod borers.
- ✓ Matures 170-180 days and yields up to 3000 kg ha⁻¹.
- ✓ This variety is released as a substitute variety for SA 1.
- ✓ The plant bears heavy flowering and maximum yield recorded under rainfed condition was 1800 kg ha⁻¹.
- ✓ Adi/Avanipattam (June-August): Thiruvannamalai, Salem, Namakkal, Madurai, Coimbatore, Dindigul, Theni, Pudukkottai, Sivagangai, Perambalur and Ariyalur.

VBN 2

- ✓ This variety is developed by hybridization and followed by selection from ICPL 341 xBSR 1.
- ✓ This variety recorded 20% more yield than SA 1 and resistant to SMD.
- ✓ It can be grown throughout Tamil Nadu during *kharif* under rainfed condition.
- ✓ It matures in 170-180 days and yields up to 1040 kg ha⁻¹. This is a substitute variety for SA 1 and Co 6.
- ✓ Adi/Avanipattam (June-August): Thiruvannamalai, Salem, Namakkal, Madurai, Coimbatore, Dindigul, Theni, Pudukkottai, Sivagangai, Perambalur and Ariyalur.
- ✓ Chithiraipattam (Summer Irrigated): All district except the Nilgiris and Kanyakumari wetland bunds.

Perennial variety

BSR 1

- ✓ This variety is a pure line selection from Myiladumparai local. This variety grows up to three years.
- ✓ This variety can be grown throughout Tamil Nadu, suitable for growing on the bunds of other crop and pod yield upto 1.5 kg plant⁻¹.
- ✓ It flowers only once in a year. The flowers are deep red in colour and its green pods are longer and bolder. Its 100 seed weight is 12-15 g.
- ✓ Chithiraipattam (Summer Irrigated): All district except the Nilgiris and Kanyakumari wetland bunds.

LRG 41

- ✓ LRG 41 is a variety of red gram (also known as pigeonpea) that is known for its tolerance to pod borer and is suitable for black soils.
- ✓ It is also adapted to conditions where irrigation is available and can be grown in lighter soils. LRG 41 has demonstrated advantages over short-duration varieties in terms of yield attributes, yield, and net returns, according to a study by the Society of Krishi Vigyan.
- ✓ Tolerance: LRG 41 exhibits tolerance to pod borer, a common pest of red gram.
- ✓ Soil suitability: It is well-suited for cultivation in black soils.
- ✓ Irrigation: Under irrigated conditions, LRG 41 can be grown in lighter soils as well.
- ✓ Yield and returns: It has shown advantages over short-duration varieties in terms of yield attributes, overall yield, and net returns.

- ✓ Intercropping: LRG 41 can be intercropped with other crops.
- ✓ Mean yield: LRG 41 recorded a mean yield of 11.0 q ha⁻¹, according to the Society of Krishi Vigyan.
- ✓ Adi/Avanipattam (June-August): Thiruvannamalai, Salem, Namakkal, Madurai, Coimbatore, Dindigul, Theni, Pudukkottai, Sivagangai, Perambalur and Ariyalur.
- ✓ Chithiraipattam (Summer Irrigated): All district except the Nilgiris and Kanyakumari wetland bunds.

APK 1

- ✓ Pure line selection from ICPL 87101- ICPL 341 x Bhavani-sagar local.
- ✓ 50% flowering (days)-70 days
- ✓ Duration days-90-105 days.
- ✓ Grain Yield (kg ha⁻¹)
 - ✚ Rainfed-900
 - ✚ Irrigated-1250
- ✓ Purattasipattam (September- October): Vellore, Thiruvannamalai, Dharmapuri, Erode, Salem, Namakkal, Coimbatore, Dindigul, Theni, Pudukkottai, Sivagangai, Perambalur and Ariyalur.
- ✓ Markazhipattam (Winter Irrigated): All district except the Nilgiris and Kanyakumari.
- ✓ APK 1 is a high yielding short duration variety released in 1999 it is suitable for all season and intercropping, and is resistant to Yellow Mosaic Virus (YMV).
- ✓ APK-1 is also known for its uniform bearing and

short stature.

Key Features

Short duration: APK-1 has a relatively short maturity period, typically 95-105 days.

High yield: It produces a good yield, around 900 kg ha⁻¹.

Suitable for all seasons: The variety is adaptable to different seasons.

Intercropping suitability: APK-1 is well-suited for intercropping with other crops.

YMV resistance: It is resistant to the Yellow Mosaic Virus, a common disease in red gram.

Uniform bearing: It produces pods uniformly along the branches.

Short stature: APK-1 is characterized by its shorter stature, making it suitable for certain

Co 9

Cross derivative: It's a cross derivative of CO 6 and IC 525427.

- ✓ CO9, also known as CRG 2012-25, is a high-yielding pigeonpea (red gram) variety developed at the Tamil Nadu Agricultural University (TNAU) in Coimbatore.
- ✓ It's suitable for the *Kharif* (wet season) planting in the southern zone of India, particularly in Cuddalore, Tamil Nadu. CO9 was released by the Central Variety Release Committee in 2019 and is known for its bold seeds and a good yield.

Key features of CO9 Red Gram

Yield: CO9 yields an average of 1700 kg ha⁻¹, showing significant increases over other varieties.

Duration: It has a long duration of 170-180 days,

suitable for *Kharif* sowing.

Seed characteristics: It has bold seeds, with 100 seed weight ranging from 9.0 to 10.0 grams.

Protein content: It has a high protein content of 23.65 percent.

Disease resistance: It's moderately resistant to wilt and some other diseases.

Seaweed as a Natural Remedy for Fish Diseases: A Sustainable Approach

Satyajit Ghoshal, Pritam Sarkar and Neha Hazra

Introduction

The rapidly expanding aquaculture food industry is confronted with numerous fish illnesses and disease outbreaks. Disease infections in aquaculture can arise from a variety of pathogenic and nonpathogenic sources. It is commonly recognized that disease outbreaks cause noticeable financial losses. Pathogenic and nonpathogenic disease conditions differ. Bacterial, viral, fungal, and parasitic conditions are examples of pathogenic conditions. Environmental and dietary factors are nonpathogenic. Therefore, rather than looking for a cure, it is essential to develop aquatic animals' immunity, which includes both specific and nonspecific immune responses, in order to prevent those difficult circumstances. The development and expansion of a prosperous and sustainable aquaculture business are seriously threatened by the careless and/or improper use of antimicrobial drugs to treat infections of farmed aquatic species. One significant effect is the rise in antimicrobial resistance (AMR), which makes it harder to treat common bacterial diseases in aquatic organism populations. Additionally, the presence of antibiotic residues in food fish and their products causes import rejections and has a detrimental effect on global trade. Seaweeds function as a natural remedy and have a strong antioxidant capability.

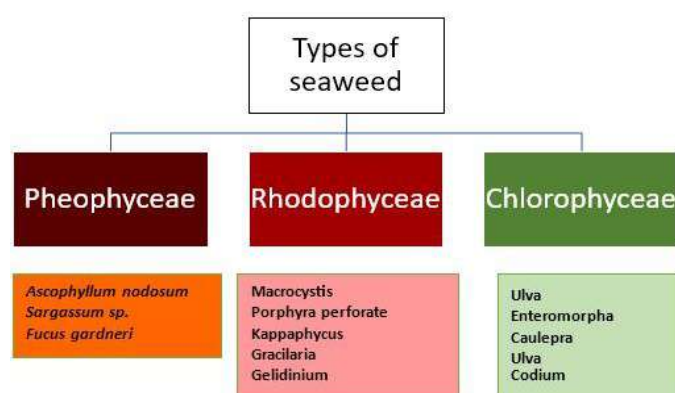
Aquatic creatures' health is impacted by bacterial fish infections. Seaweed extracts' bioactive substances shown strong antibacterial activity. They can be used as a preventative measure and to treat bacterial infections in aquaculture. Since synthetic treatments lead to resistance, this type of preventive therapy can be employed instead.

Seaweed: A Treasure Trove of Bioactive Compounds

According to FAO reports all cultivable aquatic algae recorded under different groups have been classified into several sets based on the environment in which they are found and their potential uses. The species composition of the worlds farmed seaweed production increased mainly in the tropical and subtropical marine species. Seaweed species are categorized according to their various properties based on their fundamental structural and functional characteristics. For example, the brown seaweeds are predominantly used for different syntheses, while *Gracillaria* species are commonly used for the production of feeds. It also has health benefits and is used in drug formulations. *Wakame* and *Porphyra* are farmed for human consumption. In the past few decades, seaweeds and their extracts are being increasingly used as prophylactic and therapeutic agents, and in aquaculture for aquatic health management. Most seaweeds have antimicro-

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bial activity against harmful fish and shrimp pathogens particularly in India. Two examples are *Asparagopsis* species (red algae) and *Sargassum* sp. (brown algae) which have exhibited a broad range of antimicrobial activity against pathogens (Vatsos and Rebours, 2014). The extraction of the compound responsible for their antimicrobial properties depends on various factors like the use of solvents. Organic solvents are more efficient than others. This review focus on the use of bioactive compounds from the seaweeds that have biological activities especially those which can be used for their antimicrobial activities responsible for the prevention of fish diseases. Studies on the constituents of marine algae have been carried out. Seaweed extracts are a potential source for sustainable aquaculture (Smit, 2004). The use of chemical compounds and components identified from the bioactive compounds are used as tools in medical research (Kris-Etherton *et al.*, 2002; Mayer and Lehmann, 2000).



Potential uses of marine algae in aquaculture

Seaweed extracts showed a wide range of beneficial properties such as antioxidant, promoting growth rate, anti stress, appetite stimulus, immune stimulation, boost of tonicity, and physiological

Benefits. Enhancement of aphrodisiac and anti-pathogen properties due to the presence of bioactive compounds or essential oils has been reported in aquaculture (Chakraborty and Hancz, 2011, Thanigaivel *et al.*, 2015a, Citarasu, 2010). Besides, the use of such secondary metabolites is cost efficient and also easily biodegradable when compared to synthetic particles (Logambal *et al.*, 2000, Blumenthal *et al.*, 2000).

Antioxidant activity: Several antioxidant defense systems help in restoring the normal architecture of cells which have become cancerous. These antioxidant defence systems prevent macromolecular cell damage by oxidation. Studies suggested that tumors are more vulnerable in humans and animals when they generate more free radicals during the pro-oxidant state (Boopathy *et al.*, 2013). Oxidative macromolecular damages are primarily responsible for cancer (Hajiliadis, 1997; Huang, 2003). The formation of oxidative species leads to the proliferation of cells, cell cycle arrest and apoptosis. There are few antioxidant molecules which scavenge free radicals. They are exogenous and endogenous and complement each other to control cellular redox in cancer treatment and prevention. The primary source of oxidative substances are; reactive oxygen species (ROS) and reactive nitrogen species (RNS). These substances known as hydroxyl radicals (OH). Hydrogen peroxides (H₂O₂), superoxides (O₂⁻), nitric acid (NO) and peroxyxynitrite (ONOO⁻) also damage proteins, lipids and DNA (Orrenius *et al.*, 2007; Jun *et al.*, 2001).

Therefore, it is important to characterize the isolated natural antioxidants and their potential capabilities to ascertain the side effects before commercialization (Matsukawa *et al.*, 1997; Athukorala *et al.*, 2003 and Lim *et al.*, 2002).

Antipathogenic activities: Different seaweeds screened for antimicrobial property by extracting their active compounds with various solvents like (ethanol, methanol, chloroform, petroleum ether and dichloromethane, etc.) exhibited various antimicrobial activities. (Shanab, 2007) reported more anti bacterial activity in the red algal species than the brown alga *Sargassum dentifolium*. Total chlorophylls, carotenoids, free phenolics, saturated and unsaturated fatty acids in the seaweed extracts were reported to be the active substances responsible for the antioxidant and antimicrobial activity in the red alga species (Shanab, 2007). Phenolic content was found to be higher in the ethanolic extracts because of its polarity, and these phenolics were present most abundantly in rhodophytes. The antibacterial property of marine algae (*J. corniculata* and *L. papillosa*) was reported to be due to the presence of fatty acids such as (Tetradecanoic, Hexadecanoic and Octadecanoic) and (Hexadecenoic, 9-octadecenoic and Tetracosenoic). A higher percentage of fatty acids was detected in *L. papillosa* and *J. corniculata* (Rice-Evans *et al.*, 1997 Wei *et al.*, 2003, Kang *et al.*, 2004, Yuan *et al.*, 2005). This was also reported by Daoud and Foster (1993) and Kimura and Yokota (2004). Nagayama *et al.* (2002), Kubo *et al.* (1992) and Alam *et al.* (1994)

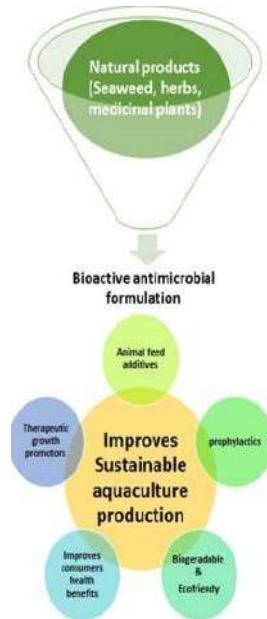
reported that these fatty acid compounds exhibited potent antimicrobial activity against different bacterial and fungal species.

Immunostimulation property of extracts: Immunostimulants are protective agents which induce non-specific immune responses towards disease resistance. Some immune stimulants which are derivatives of biological compounds of bacterial and animal origins are reported to have immune stimulation properties. The immunostimulants used in the fish and shrimp aquaculture farms are derived from barley, glucan, chitosan, saponin, and plant extracts, lipopolysaccharides, peptidoglycans etc. (Rajasekar *et al.*, 2011). Most of the fishes depend on either specific or non-specific mechanism to defend themselves against attacking pathogens just like humans. In fish, the primary defensive lines are skin and mucous membranes as a nonspecific system. During the entry of invading pathogens, the system activates phagocytosis. This process is considered as the principal mediator of non-specific immunity against various virulent pathogens in fish. However, some of the immune stimulants could not be used because of various disadvantages, on the other hand, medicinal plants are used as immune stimulants for several diseases (Duke, 1987, Mantle *et al.*, 2000, Zarkovic *et al.*, 2001, Verpoorte *et al.*, 1999). The use of immune stimulants in medicinal plants as immune prophylactics has been studied as an alternative strategy to the antibiotics. Nowadays there is growing interest in seaweeds, and their extracts and various formulated combinations of

extracts promoting activities such as growth, immunity, antibacterial and antiviral properties against host pathogens (Van Hai, 2015).

Immuno stimulants for prevention of fish diseases

The WHO (2002) has recommended the use of preventive natural plant-based approaches for illness management, mainly in agriculture and aquaculture (Verschuere *et al.*, 2000). This has stimulated research on the control of foreign protein contents which harm the environment. One of the methods of controlling foreign proteins is immunotherapy which deals with the pathogenic and immune pathogenic response towards the invader organism by controlling the action of a particular pathogen by stimulating the overall immune response of the foreign protein (Sordillo *et al.*, 1997). The use of immune stimulants is considered as an alternative method to control or prevent the fish diseases (Sakai, 1999). Thanigaivel *et al.*, 2014; Thanigaivel *et al.*, 2015 reported the possibility of using seaweed extracts for controlling diseases in both shrimp and fishes, opening up the possibility of using seaweed extracts as a source of immune stimulants. For the past two decades, numerous chemotherapeutics have been used to treat various bacterial infections in cultured fishes and shrimps, but the occurrence of multiple drug-resist-



ant bacteria is a major problem (Aoki, 1992). The administration of an active vaccine may also preclude fish diseases. A supplementary practical method of controlling bacterial diseases in aquaculture appears to be the enhancement of natural disease resistance by using immune stimulants (Sakai, 1999).

Scientific Evidence and Recent Studies

Case Study 1: In a recent study conducted by the sayedalhosini *et al.*, 2024 on the Effect of Dietary Seaweed (*Gracilaria pulvinata* and *Sargassum ilicifolium*) on Serum and Mucosal Immunity, Some Growth and Immune-Related Genes Expression, Antioxidant Status, and Fatty Acid Profile in Asian Seabass (*Lates calcarifer*) found that the serum and lysozyme activity were significantly higher when they are feed with Gracialaria. The activities of the alkaline phosphates, skin mucus lysozyme, Antioxidant properties and the fatty acid profile in case of the juvenile *L.calcarifer*.

Case study 2: According to a study on Investigation of seaweed extracts as a source of treatment against bacterial fish pathogen by Thanigaivel *et al.*, 2015, the sea weed extracts are excellent source of antimicrobial compounds. These can be used for treating bacterial infection as an alternative to antibiotics which cause resistance. The extracts are found to be nontoxic and can be used in aquaculture industries for treating bacterial infection.

Case study 3: In another study of protective efficacy of microencapsulated seaweed extracts for preventing *Aeromonas* infections in *Oreochromis mossam-*

bicus by Thanigaivel *et al.*, 2018 found that the treatment of *A. salmonicida* infection in *O. mossambicus* using formulated bioactive compounds obtained from *Gracilaria foliifera* and *Sargassum longifolium* showed very high survival percentage in this species of fish.

Future areas that need focus

Complete information on the quantitative nutrient requirement and disease prevention by natural products such as bioactive compounds in most fishes is lacking. Therefore this is the hot spot where future research needs to be carried out. Another important area where further research need to focused is the controlled release of the bioactive compounds extracted from the seaweeds which are encapsulated in the form of effective aqua feeds. Its bioavailability in large scale farming requires more attention.

Conclusion

This detailed review discussed an overview of using seaweed extracts as an alternative strategy to control infections in aquaculture. Marine macro algae which are readily available and inexpensive are the most suitable because they are not only useful but also harmless to beneficial bacteria like probiotics. These natural immune stimulants which induce immune stimulant and antipathogenic activity can be used instead of synthetic antibiotics which cause resistance to the organisms. Hence, this bio-based mediated defense process is helpful when the pathogenic organisms attack the fishes and shrimps leading to various symptoms and mass mortalities in

farms. Moreover, the use of seaweed extract based products for treatments in aqua farms is considered as a biodegradable and eco-friendly approach, since it maintains a clean aquatic environment which directly and indirectly enhances the aquatic animal health. Marine seaweeds and their metabolite based treatment can control infections caused by the pathogenic organisms. The administration strategy of seaweed extracts depends on the bioactive compounds and its controlled release in the aquatic environment which is most promising by dispersion. However, its bioavailability in large scale farming is yet to be studied. The use of seaweed extracts in a colloidal mixture of two or more beneficial bioactive compounds for the treatment of bacterial infections was studied *in vivo* and *in-vitro* in the laboratory. These substances probably act by affecting the quorum sensing mechanism of bacteria limiting its growth (Thanigaivel *et al.*, 2015). While focusing on the prospects for controlling or treating the pathogenic infection in fish farms and hatcheries, the wide range of bio-based natural processes available need to be given importance to ensure that the aquatic ecosystem remains clean and more productive. Various bio-encapsulation techniques can also be developed by using the different biologically synthesized matrices to deliver the desired compounds or secondary metabolites such as protein, minerals, carbohydrates, fats, fibers and vitamins by integrating them into the models to ensure that the best nutritional feeds for the growth of various fishes and shellfishes are available.

Bioactive compounds extracted from the seaweeds which have antibacterial activity are encapsulated. These extracts are added to the commercially available feeds (live or dry), to stimulate immune response to act directly against the fish pathogens. This method of encapsulation of the active fractions of seaweeds and its phyto compounds in the different matrices like sodium caseinate and alginate needs to be popularized. In conclusion, we state that the bioactive compounds encapsulated in the feed in the form of beads can be used for treating bacterial infection in fish and shellfish aquaculture.

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Balancing Livelihoods and Biodiversity: A Rural India Perspective

Manas Jyoti Borah and Priyanka Hatimata

Abstract

In rural India, particularly Assam's biodiversity-rich landscapes, human-wildlife conflict jeopardizes farmers' livelihoods and conservation goals. Elephants, leopards and wild boars destroy crops and livestock, causing economic losses, while habitat loss and fragmented migration paths push wildlife into villages. These conflicts burden small farmers, who form over 50% of India's workforce, with debt and food insecurity. Case studies from Sonitpur and Tipi Elephant Corridor showcase community-led solutions like forest restoration, wildlife-resistant crops and bio-fencing, reducing conflicts by up to 20%. The study highlights empathetic, practical approaches - smart technology, crop insurance, infrastructure upgrades and community engagement to foster coexistence, ensuring sustainable agriculture and biodiversity for rural India's future.

Introduction

In the heart of rural India, where golden fields meet ancient forests, a quiet struggle unfolds daily. Some farmers spend sleepless nights guarding their crops and livestock from wildlife-elephants trampling fields, leopards attacking goats and wild boars ruining harvests. This human-wildlife conflict, especially in biodiversity-rich areas like Assam, is more than a clash between animals and people. It's a challenge to farmers' livelihoods, food security and the dream of living in harmony with nature. As India's population grows and forests shrink, we need kind, practical solutions to create a future where both humans and wildlife can thrive.

The Scale of the Struggle

The numbers tell a heartbreaking story, particularly in Assam, where human-elephant conflicts

leave deep scars. From 2015 to 2023, the Assam Forest Department recorded 802 human deaths and 586 elephant deaths. Elephants destroy thousands of hectares of paddy, sugarcane and banana crops annually, damaging over 1,000 homes. Across India, 474 elephants were electrocuted between 2014 and 2020, 90 in Assam, often by unsafe field wiring. Leopards and tigers kill over 10,000 livestock yearly, as per the Wildlife Protection Society of India. These losses represent shattered harvests and families fighting to survive.

Why this Happens

The conflict arises from human expansion and nature's limits. Since 1990, India lost 23.28 million hectares of forest to infrastructure and agriculture, pushing wildlife into villages. Degraded forests, overgrazing and broken migration routes

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blocked by highways and settlements force hungry animals toward crops. Poor waste management attracts monkeys and boars to village garbage. With India's population projected to hit 1.5 billion by 2030, the human-animal divide is fading fast.

The Impact on Farmers and Agriculture

For farmers, who support over 50% of India's workforce, the toll is crushing. A single elephant can ruin a year's harvest, while birds, rodents, and monkeys destroy up to 55% of crops, as per the Indian Council of Agricultural Research (ICAR). In Assam, wildlife-related crop losses cost ₹500-1,000 crore annually, hitting small farmers 80% of India's farming population hardest. Livestock losses to predators, with compensation covering only 20-30% of value, deepen the pain.

The ripple effects include

Economic Strain: Crop losses drive debt, with 52% of farming households indebted, per the National Sample Survey Office. Repeated investments in seeds and fertilizers cost ₹14,000 per hectare.

Food Security: Damaged crops reduce local food supplies, especially in rain-fed areas (60% of farmland), raising prices.

Time and Labor: Fear of wildlife limits night work, while repairing damage adds unpaid labor.

Mental Toll: Constant vigilance causes stress, with legal risks under the Wildlife Protection Act of 1972.

Environmental Impact: Trampling compacts soil, and damaged irrigation disrupts water flow. Farmers abandon diverse crops like millets, dropping 20% in conflict zones, per ICAR, harming soil health.

Broader Issues: Disrupted supply chains, limited government procurement (14% of farmers), and rural youth leaving agriculture (10% drop from 2011-2020) threaten rural stability.

Stories of Hope: Case Studies

Sonitpur's Turnaround: In Assam's Sonitpur district, elephant raids once devastated farms after 30% of Sonai Rupai Wildlife Sanctuary's forests vanished between 1990 and 2005. The Assam Forest Department and NGOs like 'Aaranyak' replanted native trees and secured migration paths, cutting conflicts by 15% since 2018. Farmers adopted chilli-based and thorny bio-fences, protecting crops harmlessly and grew elephant-resistant turmeric, reducing losses by 25%. This shows local wisdom can safeguard both farms and wildlife.

Tipi Elephant Corridor's Transformation: In the Tipi Elephant Corridor (Assam-Arunachal Pradesh), 40% of greenery was lost to tea plantations by 2009. Conservationists and estate owners planted shade trees and created water bodies, guiding elephants away from farms and cutting crop damage by 20%. Farmers switched to ginger and chilli, boosting incomes by 15%. This model proves commercial lands can balance agriculture and biodiversity.

Paths to Peace

Resolving this conflict demands science, empathy and practical steps:

Forest Restoration: India's goal to increase forest cover by 10% by 2030, via initiatives like Amrit Brikhya Andolan, gives wildlife space, reducing farm raids.

Wildlife-Friendly Farms: Tea estates can plant buffer zones, as in Tipi, protecting crops and biodiversity.

Smart Infrastructure: Wildlife bridges (e.g., Uttarakhand) and GPS-triggered train lights (Odisha) cut animal deaths by 70%. Assam's 4-km solar fencing in Goalpara mitigates elephant conflicts.

Technology: Drones, infrared cameras and AI apps (e.g., Karnataka) predict animal movements, reducing damage by 30%.

Non-Lethal Deterrents: Beehive fences (Kerala), chilli sprays and safe solar fences repel animals harmlessly.

Crop Choices: Wildlife-resistant turmeric, ginger, and lemongrass cut losses by 30% and boost incomes, per ICAR. Joint Forest Management's fodder crops reduce animal reliance on farms.

Insurance and Credit: Wildlife-tailored crop insurance, like PMFBY and low-interest loans ease financial burdens.

Communities at the Core

Farmers and villagers must lead. Youth trained as Anti-Depredation Squads, as in Kaziranga, protect fields. Kaziranga's E-eye surveillance and WhatsApp alerts cut response times by 50%. Village meetings and school programs foster empathy for wildlife. Fair compensation via mobile apps, as in Maharashtra, pays 80-100% of losses within 30 days. Enforcing laws against illegal retaliation and tracking 5,000 animals with radio collars by 2030 will refine solutions.

A Vision for Harmony

This is about securing India's rural future, where farmers- 60% of the workforce feed 1.4 billion people while bearing conservation's costs, like growing elephant (30,000) and tiger (3,167) populations. By blending forest restoration, smart farming, technology and community strength, India can create fields where crops grow, wildlife thrives and families prosper. With shared effort, we can move from conflict to coexistence, preserving India's biodiversity and agricultural heritage for generations.

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Biofortification for Healthier Harvests: A Scientific Response to Iron and Zinc Deficiency

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Abstract

Micronutrient malnutrition, often referred to as “hidden hunger,” affects over two billion people globally, with zinc and iron deficiencies being among the most prevalent and debilitating. These deficiencies compromise immune function, cognitive development, and overall health, especially in vulnerable populations such as children and pregnant women. Biofortification, the process of enhancing the nutritional content of food crops through biological means, has emerged as a sustainable and cost-effective approach to combat micronutrient deficiencies. Several approaches are employed in biofortification, including conventional plant breeding, agronomic practices (such as micronutrient fertilization), and modern biotechnological tools like genetic engineering and genome editing. Among these, breeding zinc- and iron-rich varieties of rice, wheat, maize, and beans has shown significant promise, supported by initiatives like Harvest Plus. Agronomic biofortification using zinc- and iron-enriched fertilizers also offers immediate but short-term solutions, particularly in soils deficient in these elements.

Introduction

Malnutrition is a broad term to indicate the conditions that may arise from both undernutrition and overnutrition. Undernutrition is associated with stunting (low height for age), wasting (low weight for height), being underweight (low weight for age) and micronutrient deficiencies, whereas overnutrition is associated with obesity, diet-related noncommunicable diseases (e.g., heart disease, stroke, diabetes and cancer) and being overweight. Undernutrition is defined as the provision of an insufficient quantity of food (hunger) or the provision of a sufficient quantity of food but with low levels of essential food elements (i.e., hidden hunger). Hunger is usually understood to refer to the

suffering associated with lack of food, but can also refers to conditions when a sufficient quantity of food is provided with low levels of minerals and vitamins. Micronutrients play an important role in the proper growth and development of the human body and its deficiency affects the health contributing to low productivity and vicious cycle of malnutrition, underdevelopment as well as poverty. Micronutrient deficiency is a public health problem affecting more than one-fourth of the global population. Several programmes have been launched over the years in India to improve nutrition and health status of the population; however, a large portion of the population is still affected by micronutrient deficiency.

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Anaemia, the most common form of micronutrient deficiency affects almost 50 to 60 per cent preschool children and women, while vitamin A deficiency and iodine-deficiency disorders (IDD) have improved over the years. Nutritional insecurity is a major threat to the world's population that is highly dependent on cereals-based diet, deficient in micronutrients. Cereals and millets are nutritionally superior as their grains contain high amount of protein, essential amino acids, minerals, and vitamins. Biofortification of staple crops is proved to be an economically feasible approach to combat micronutrient malnutrition. Some groups and NGOs in India realized the importance of crop biofortification and released conventionally bred high iron and zinc rich crops in India to tackle iron deficiency.

Role of zinc in plant system

Zinc is constituent of enzyme: Zinc plays an important role in the structure and function of many enzymes, including alcohol dehydrogenases (ADHs) of the MDR type (mediumchain dehydrogenases/reductases). Active site zinc participates in catalytic events, and structural site zinc maintains structural stability.

Protein metabolism: Co-factor of a large no. of enzymes involved in "protein synthesis & also involved in stability and functioning of genetic material.

Carbohydrate metabolism

Photosynthesis: Constituent of Carbonic anhydrase (CA) enzyme, which have role in CO₂ fixation. CA contains a single Zn atom which catalysis the hydra-

tion of CO₂.

Sucrose and Starch Formation: Component of aldolase which involved in sucrose formation coupled with important role in starch metabolism.

Detoxification of super oxide radicals: Zn involved in the 2 enzyme Cu-Zn-SOD (most abundant SOD in plant).

Anaerobic root respiration: Carbonic anhydrase is involved in root respiration and Zn is a part of it.

Membrane integrity: Structural orientation of macromolecules and maintenance of ion transport systems.

Auxin metabolism: Required for synthesis of Auxin, while reduction in Zn reduces the level of auxins in plants.

Uptake and Stress: Water uptake and transport in plants and alleviate short prairies of heat and salt stress.

Synthesis of cytochrome C: Cytochrome c is primarily known for its function in the mitochondria as a key participant in the life-supporting function of ATP synthesis.

Role of iron in plant system

Chlorophyll production: Helps in formation and maintenance of chlorophyll.

Part of protein: As iron is a part of protein helps in formation of amino acids.

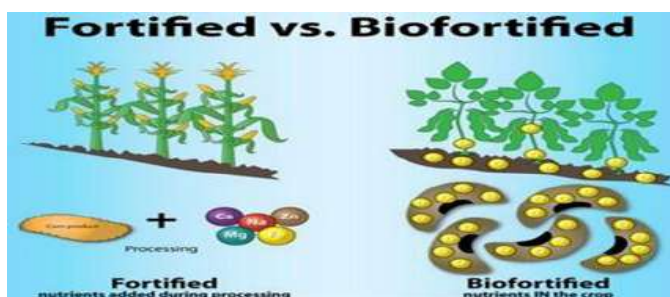
Oxygen carrier: During respiration act as oxygen carrier.

Catalase in N₂ reductase: Helps in nitrate reductase

Biofortification

Greek word "bios" means "life" Latin word

“fortificare” means “make strong”. Biofortification is the process of enrichment of food crops that are rich in bio available micronutrients, such as vitamin A, zinc and iron through agronomic practices, conventional plant breeding or modern biotechnology. Biofortification is a relatively new intervention to improve human nutrition worldwide, with a special emphasis on the populations of poor and developing countries. There are several ways to improve the nutritional value of food crops. The basic goal of biofortification is to reduce mortality and morbidity rates related to micronutrient malnutrition and to increase food security, productivity and the quality of life for poor populations in developing countries. Biofortification could provide a range of certain micronutrients for people who don’t have access to other interventions. As staple foods are comparatively cheap and accessible to the majority of people, the biofortification of staple crops is a primary target. Although the efficiency of biofortification is not comparable to food supplementation, it can still help reduce the micronutrient intake gap and increase the daily intake of vitamins and minerals throughout a person’s life and this may have significant impact on human health by reducing malnutrition. Indeed, improved micronutrient concentrations in several crops.



Biofortification Approaches

Biofortification can be agronomic and/or genetic. Genetic biofortification can be accomplished either through conventional breeding or through genetic engineering to enhance micronutrient levels in edible plant parts. Mineral elements deficiencies in food crops may be due to different factors, such as soils which are deficient in one or more minerals, lowered availability of minerals to plants due to different factors such as alkaline soils, reduced distribution/translocation of minerals and accumulation of minerals in nonedible parts of food crops. Thus, it is extremely important to address these issues to increase the mineral levels in the edible parts of the crop plants.

Conventional Plant Breeding: Conventional breeding have the potential to deliver the required targets; nevertheless, when genotypic variation for any specific nutrient is low, then conventional breeding is unable to achieve the target. Under such conditions, genetic engineering can contribute to increase the micronutrient content in staple crops and its potential has been successfully demonstrated. Enhanced uptake from soil, improved transport of micronutrients to shoot and grains, augmented sequestration of minerals to endosperm and reduction in antinutritional factors in grains are the major targets of biofortification research and genetic biofortification can target these aspects for mineral biofortification. Despite the potential of GM technology to improve human health, problems in approval of GM-biofortified crops caused by regulat-

ory barriers significantly hinder the effectiveness of GM technology for biofortification. On the other hand, conventionally biofortified crops are significantly contributing to the amelioration of mineral deficiencies.

Cross Breeding: This technique has been used since the 1700s, it's when you take two sexually compatible crops and cross pollinate them to produce a hybrid. Some examples are the plumcot (plum and apricot), tangelos (tangerine and grapefruit), the limequat (lime and kumquat) and most famously the rabbage (cabbage and radish).

Mutagenesis: Mutations (muta) are genetic changes that can switch, add, or delete nucleotides (those A, T, G and C bases), these genetic changes can sometimes lead to new/enhanced traits which is why plant breeders sometimes induce (genesis) these genetic changes using radiation or chemicals. This technique in the first half of the 20th century. For example, radiation was used to produce a deeper color in the red grapefruit.

Protoplast Fusion: It's actually when you take two plant cells which have their hard cell walls removed (Protoplasts) and you add a chemical called polyethylene which allow the two cells to stick together. Once they are stuck together basic chemicals are added to help the two cells combine and exchange genetic information to create a hybridized plant cell (fusion). It's much like cross breeding, except it's done in a lab.

Polyploidy: We, humans, are diploid animals, which mean we have two sets of homologous 13 chromo-

somes. Polyploidy have more than one, and the induction of polyploidy is used by plant breeders to control reproduction. Introducing polyploidy by soaking seeds in colchicine can either make sterile crosses fertile, like the Triticale (hybrid of wheat and rye), or sterilizes crops, like watermelon, to make seedless strains.

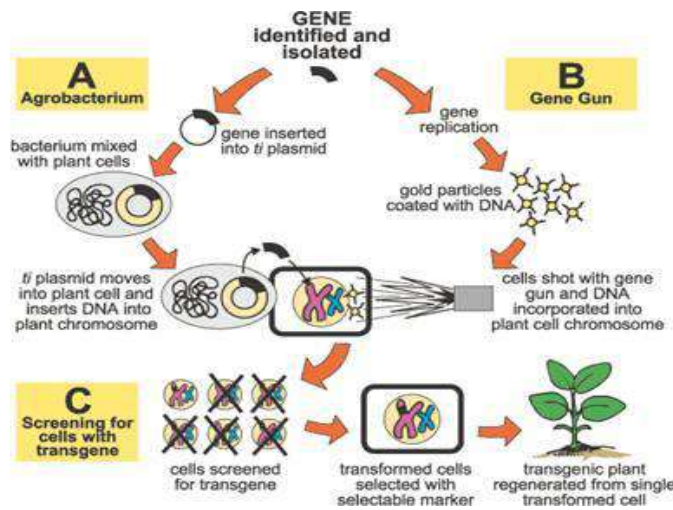
Genome Editing: This process has the ability to cut, replace or insert genes within the seed cells using "molecular scissors" called nucleases enzymes which have the ability to loosen, remove and add nucleotides. These nucleases are artificially engineered to accurately place in desired genes, or traits, into the genome of the crop. Herbicide tolerant canola was created using this technique to help farmers control weeds.

Transgenesis: When genes from one crop are incorporated into another crop. Since the genetic code is readable by all living organisms, this means that the genes introduced will code for the same proteins as it did before. There are many ways to introduce these new genes, like using agrobacterium to carry it into the genome, or using electricity.

Genetic Engineering

Genetic engineering methods can be used to increase the trace element content of staple foods such as cereals and legumes, which can be achieved by insertion of genes with the ability to produce the desired nutrients that are typically deficient. It may involve the identification and insertion from another source, or deletion of a gene to improve the desired trait like micronutrient density.

This may be achieved by the introduction of genes that code for trace element-binding proteins, over expression of storage proteins already present or the expression of other proteins that are responsible for trace element uptake into plants.



Agronomic Bio-fortification

Agronomic biofortification is the application of micronutrient-containing mineral fertilizer to the soil and/or plant leaves (foliar), to increase micronutrient contents of the edible part of food crops. Nongenetic measures to improve the micronutrient concentrations of food plants could be more efficient and several strategies and measures can be adopted to increase micronutrient concentrations in the edible parts of food plants. These include management practices, fertilization of target elements and improving soil organic matter to increase nutrient availability in soil and its uptake by roots. There is evidence that agronomic biofortification not only increases yields but also the nutritional quality of staple crops. Micronutrient fertilization is most effective when using a combination of inorganic and organic fertilizers, highlighting the

importance of integrated soil fertility management. Fertilizer application is an immediate and effective route to enhance trace elements concentrations in crops; nevertheless, genetic biofortification may be more cost effective in the long term. Selenium fertilization in Finland has already been adopted, and its impact on increasing selenium concentrations in Finnish foods and optimum dietary intake by humans has been reported. The biofortification of crops with vitamins through agronomic measures is not feasible; however, agronomic measures have shown enormous potential to increase mineral concentrations. Foliar fertilization is based on the application of nutrients directly on the plants leaves. Absorption occurs either via cuticular or via stomatal pathway. Nutrient absorption via stomata can be further enhanced by using surfactants. Recently, nutrients in the form of microparticles ($< 4 \mu\text{m}$) were launched on the market. These are expected to have improved ability to be absorbed and utilized in the plant tissues. Application with surfactant improves absorption of microparticles by stomatal pathway. Mobility of compounds within the plant tissues is of great importance, because it improves utilization of nutrient applied.

Conclusion

Biofortification stands as a transformative solution in the global effort to reduce micronutrient malnutrition, particularly the widespread deficiencies of iron and zinc. By leveraging scientific advances in plant breeding, agronomic practices, and modern biotechnological tools, biofortification

offers a sustainable and cost-effective pathway to enhance the nutritional quality of staple crops. This approach not only improves human health outcomes such as better immune function, cognitive development and maternal health but also reinforces food systems that are resilient and inclusive. As the demand for nutrient-dense food continues to rise, the integration of biofortified crops into agricultural and public health strategies will be crucial.

Application of Data Envelopment Analysis (DEA) in Agriculture

Manoj Kanti Debnath, Bharat Kumar Marmat and Ajith S.

Abstract

Data Envelopment Analysis (DEA) is a non-parametric technique used to measure efficiency by comparing multiple inputs and outputs. It helps optimize resource use in agriculture, improving productivity and sustainability. DEA models like CCR and BCC assess technical and scale efficiency, aiding decision-making. In India, DEA identifies best practices and guides policy for better farming outcomes. Despite challenges like data limitations, DEA remains a valuable tool for agricultural efficiency analysis.

Introduction

Data Envelopment Analysis (DEA) is a non-parametric method that uses mathematical programming to assign an efficiency score to each unit, known as a Decision-Making Unit (DMU). DMUs are entities that use inputs to generate outputs within a shared framework, which may not always be easily quantifiable in market terms. DEA is particularly relevant to non-profit organizations, such as educational settings, where efficiency is evaluated based on outputs like cognitive skills, psychological attitudes, and physical abilities. In agriculture, efficiency refers to the optimal utilization of resources like land, water, labour, and inputs to achieve the highest output while minimizing waste and costs. DEA is frequently employed to assess the efficiency of farms, businesses, or organizations in agriculture.

The efficiency score does not exceed one, as it is the ratio of weighted outputs to weighted inputs. DEA uses linear programming to compare multiple inputs and outputs, assessing how well a unit performs relative to others. These scores range from 0 to 1, with 1 indicating full efficiency. DEA has become a widely adopted tool across various sectors, particularly in agriculture, where it aids farmers in assessing the efficiency of land, labour, and capital for crop and livestock production. By comparing farms with similar resources, DEA identifies best practices and areas where inputs can be optimized to maximize output and profitability.

DEA models: There are two main DEA models

CCR Model (Charnes, Cooper, Rhodes): Assumes constant returns to scale (CRS), suitable when all units operate at an optimal scale (Charnes *et al.*, 1978). It estimates the gross efficiency of a DMU

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(Ramanathan, 2003).

BCC Model (Banker, Charnes, Cooper): Assumes variable returns to scale (VRS), useful when some units operate at different scales and measures pure technical efficiency (Banker *et al.*, 1984).

CCR Model: It can be input-oriented (minimizing inputs for given output) or output-oriented (Maximizing output for given input) (Malana and Malano, 2006). Due to the specificity of agriculture sector which rely on a limited input, an input-orientated model is more appropriate. The model uses the several following notations to measure the efficiency: 'n' number of DMUs; each using 'm' inputs and produces 's' outputs; for DMU 'j', x_{ij} of input 'i' and produces y_{rj} of output 'r'; The linear programming model assigns weights, ' θ ' to calculate the efficiency; S_i^- and S_r^+ are input and output slacks and ' ε ' is very small positive real number used to avoid issues like division by zero in the mathematical formulations (Markovits-Somogyi, 2011).

$$\begin{aligned} \text{Input-oriented Programming:} \quad & \text{Min } \theta + \varepsilon [\sum_{i=1}^m S_i^- + \sum_{r=1}^s S_r^+] \\ \text{Subject to:} \quad & \sum_{j=1}^n x_{ij} \lambda_j + S_i^- = \theta x_{i0}, \quad i = 1, 2, \dots, m \\ & \sum_{j=1}^n y_{rj} \lambda_j - S_r^+ = y_{r0}, \quad r = 1, 2, \dots, s \\ & \lambda_j, S_i^-, S_r^+ \geq 0, j = 1, 2, \dots, n \end{aligned}$$

$$\begin{aligned} \text{BCC Model:} \quad & \text{Input-oriented Programming:} \quad \text{Min } \theta + \varepsilon [\sum_{i=1}^m S_i^- + \sum_{r=1}^s S_r^+] \\ \text{Subject to:} \quad & \sum_{j=1}^n x_{ij} \lambda_j + S_i^- = \theta x_{i0}, \quad i = 1, 2, \dots, m \\ & \sum_{j=1}^n y_{rj} \lambda_j - S_r^+ = y_{r0}, \quad r = 1, 2, \dots, s \\ & \sum_{j=1}^n \lambda_j = 1, \quad \lambda_j, S_i^-, S_r^+ \geq 0, j = 1, 2, \dots, n \end{aligned}$$

The CCR model calculates technical efficiency (TE), while the BCC model measures pure technical efficiency (PTE). By comparing these scores, scale efficiency (SE) is determined, showing

potential productivity gains from achieving the optimal DMU size.

$$SE = \frac{TE}{PTE}$$

Since then, many improvements have been made to suit different socio-economic studies (Cook and Seiford, 2009). In simple terms 'DEA helps us understand how well a unit is using its resources (inputs) to produce desired results (outputs). For example, in agriculture, inputs could be seeds and fertilizers, and outputs could be the crop yield. By applying DEA to this data, we can find out how efficiently different sectors or states are performing.

There are 4 Steps in DEA

Selection of DMUs: Choosing states or sectors as units for analysis.

Identification of Inputs and Outputs: Defining resources used and results achieved.

Efficiency Calculation: Using mathematical models to compute efficiency scores.

Comparison: Identifying which units are efficient and which are not.

A comprehensive analysis of the application of Data Envelopment Analysis (DEA) in agriculture has uncovered a significant number of studies, with over half published in recent years. This pattern indicates a growing interest among agricultural researchers in utilizing DEA for efficiency assessments in farming, agribusiness, and resource management. Fare (1985) was the first to introduce the frontier concept within agricultural economics. Ceolli (1995) conducted a literature review on estim-

ating frontier functions and measuring efficiency, highlighting their potential relevance in agricultural economics. Sharma *et al.* (1997) employed DEA alongside the stochastic frontier production function to assess the productive efficiency of Hawaii's swine industry, concluding that DEA offers a more robust measure of efficiency compared to parametric methods.

In the early 1990s, a new research avenue emerged, with studies by Lim and Shumway (1992), Chavas and Aliber (1993), and Ray and Bhadra (1993) applying DEA to agriculture to explore whether economic efficiency stemmed from scale or scope efficiency, cost minimization, or profit maximization. Subsequent research by Tauer and Stefanides (1998) and Fraser and Cordina (1999) evaluated the efficiency of dairy farms, while Iraizoz (2003) investigated the technical efficiency of horticultural production in Spain.

In the Indian context, the country's extensive agricultural landscape faces several challenges, including small landholdings, insufficient irrigation, and limited adoption of modern technologies (Calicioglu *et al.*, 2019). Some farms manage to achieve higher crop yields with the same resources, while others do not. DEA plays a crucial role in comparing farms based on their utilization of land, labor, water, and machinery for crop production. For example, if two farmers operate on identical land sizes and utilize the same tools, but one produces a greater crop yield, DEA can help pinpoint which farmer is using resources more efficiently and which

one requires improvement.

Advantages

DEA is beneficial to Indian farmers since it determines if small farms are as productive as larger farms and provides measures to increase efficiency. It also encourages improved water management by finding farming techniques that conserve water while preserving crop yields. Furthermore, DEA emphasizes the role of technology, such as tractors, improved crops, and fertilizers, in increasing production and guiding farmers to make better investment decisions. Furthermore, by identifying the most efficient farms, the government may promote best practices throughout the industry, resulting in higher food production and better food security for the population. By using DEA, India can find solutions to improve farming, increase food production, and support farmers in using their land and resources more effectively.

Limitations

- ✓ A potential issue is the insufficient data available for each individual DMU, which can hinder accurate performance analysis. This tends to be a more significant problem in the private sector compared to the public sector.
- ✓ In the context of large-scale agricultural systems, DEA models can become quite intricate and challenging to implement, particularly when managing numerous variables such as weather, GIS, multiple years of data, and diverse farming practices.

Conclusion

This article examines the use of DEA in agriculture, emphasizing its methodological framework, practical applications, limitations, and future prospects. DEA improves agricultural efficiency by identifying optimal practices and enhancing resource utilization. It aids farmers and policymakers in boosting productivity and sustainability. In India, DEA addresses issues like small landholdings and technological gaps. Despite data limitations, DEA remains vital for informed decision-making, potentially leading to improved food security and sustainable farming practices.

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Elephant Foot Yam: A Promising Crop for Sustainable Agriculture

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Introduction

Elephant foot yam (*Amorphophallus paeoniifolius*), commonly known as “Suran” or “Jimikand” in India, is an underground tuber crop belonging to the Araceae family. Grown predominantly in tropical Asia, this crop has gained attention for its ability to thrive in marginal soils, withstand erratic rainfall, and yield substantial economic returns. As agriculture transitions towards more sustainable models, crops like elephant foot yam that require minimal inputs while delivering multiple benefits are gaining prominence (Nedunchezhiyan *et al.*, 2008).

Botanical and Agronomic Characteristics

- ✓ Elephant foot yam is a perennial herbaceous plant with a large underground corm, which stores nutrients and supports the plant's growth.
- ✓ The above-ground portion consists of a single large tripartite leaf, which emerges from the corm annually.
- ✓ The plant reaches a height of about 1-1.5 meters. It requires a warm and humid climate, with an optimal temperature range of 25-35°C and annual rainfall between 1000 to 1500 mm.
- ✓ The plant grows well in well-drained loamy soils with a pH range of 5.5 to 7.5.

- ✓ However, it has shown adaptability to red lateritic and alluvial soils as well.
- ✓ The crop matures in 7-9 months, and the corm can reach up to 15-20 kg in weight under improved cultivation practices (Ravi *et al.*, 2009; Suja *et al.*, 2010).
- ✓ It is tolerant to drought and salinity to some extent, which makes it suitable for cultivation in areas affected by climate change.

Nutritional and Medicinal Value

- ✓ Elephant foot yam is a rich source of carbohydrates, primarily starch, and dietary fiber.
- ✓ It contains significant amounts of micronutrients such as potassium, calcium, iron, phosphorus, and magnesium.
- ✓ The crop also provides bioactive compounds including phenols, flavonoids, and tannins, which possess antioxidative, anti-inflammatory, and antimicrobial properties (Singh *et al.*, 2016; Roy *et al.*, 2015).
- ✓ Medicinally, it has been used in traditional systems such as Ayurveda, Siddha, and Unani.
- ✓ It is known to be effective in treating piles, dysentery, rheumatism, and asthma.
- ✓ Recent pharmacological studies have suggested its role in controlling obesity, lowering cholest-

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erol and managing diabetes due to its glycemic index-lowering potential (Kumar *et al.*, 2018).

- ✓ Extracts from the corm have also shown anticancer properties in laboratory studies.

Cultivation Practices

- ✓ The propagation of elephant foot yam is done using healthy corm pieces weighing around 500 g to 1 kg.
- ✓ Land preparation involves deep ploughing followed by application of organic manure such as farmyard manure (FYM) or compost at 25-30 t ha⁻¹. Raised beds or mounds are recommended for better drainage.
- ✓ Planting is done during the onset of monsoon with a spacing of 60 x 60 cm or 90 x 90 cm. Application of fertilizers at the rate of 80:60:80 kg ha⁻¹ of NPK is recommended, along with micronutrients like zinc and boron in deficient soils (Nedunchezhiyan *et al.*, 2012).
- ✓ Weeding, earthing up, and mulching are necessary cultural practices to enhance crop yield. Intercropping with legumes such as cowpea or short-duration vegetables is a common practice to improve land productivity and soil health.

Economic Potential

- ✓ The market value of elephant foot yam is influenced by its demand in fresh and processed forms.
- ✓ The average yield ranges from 30-40 tonnes per hectare under irrigated conditions, with a gross income potential of INR 3-4 lakhs per hectare.

- ✓ The crop is in high demand in southern and eastern Indian states, where it forms a part of traditional cuisine.
- ✓ Elephant foot yam is also gaining importance in processed food industries for making chips, flour, and medicinal powders. Its long shelf life (up to 4-5 months under proper storage) allows farmers to sell the produce during off-season for better prices. Studies conducted by the Central Tuber Crops Research Institute (CTCRI) show a benefit-cost ratio ranging from 2.5 to 3.5 (CTCRI, 2017).
- ✓ Moreover, the crop fits well into integrated farming systems and agroforestry models, providing a regular source of income for small-holder farmers. It has also been recommended for inclusion in tribal development and rural employment programs due to its low input requirements and high economic returns (ICAR, 2021).

Challenges and Future Prospects

Despite its advantages, elephant foot yam cultivation is limited by factors such as scarcity of disease-free planting material, poor extension services, and lack of organized marketing channels. Diseases like collar rot and pests such as scale insects can affect yields if not managed properly. Post-harvest handling and mechanization are also underdeveloped in many areas.

Research institutions like ICAR-CTCRI are actively working on high-yielding and disease-resistant varieties, improved agro-techniques, and

value addition technologies. Public-private partnerships can play a significant role in promoting this crop at a commercial scale. Farmer training, availability of quality inputs, and credit support are essential to enhance its adoption.

With climate change posing a threat to conventional agriculture, crops like elephant foot yam with their resilience and adaptability offer a viable alternative. Their role in ensuring food and nutritional security, especially in rural and tribal regions, is increasingly being recognized.

Conclusion

Elephant foot yam offers a unique combination of nutritional value, medicinal utility, and economic returns, making it a highly promising crop for sustainable agriculture. Its adaptability to marginal lands, tolerance to stress, and compatibility with intercropping systems position it as an ideal candidate for diversification and climate-resilient farming. With appropriate policy interventions, research support, and market development, elephant foot yam can significantly contribute to rural livelihoods and food security.

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Boosting Farmers' Earning with Greenhouse Cultivation

Umesh Singh, Manisha Sahu and Deepika Sahu

Introduction

The present agricultural scenario in India is a mix of outstanding achievements and mixed opportunities. To emerge as an economic power in the world, India need to increase it's agricultural productivity to match other countries and for that we will need new technologies which can continuously improve productivity and sustainability of our major farming systems. One such technology, though old but new to India with benefits such as controlled environment, energy optimization and increasing yield is emerging at a rapid rate. Green house technology needed because of the world population is increasing rapidly, cultivable area is decreasing day by day, productivity of land has become stable. So we need a technology, which gives more production per unit area. Greenhouses are frames of inflated structure covered with a transparent material in which crops are grown under controlled environment conditions. These structures range in size from small sheds to industrial-sized buildings. The interior of a greenhouse exposed to sunlight becomes significantly warmer than the external ambient temperature, protecting its contents in cold weather. Greenhouses for controlled environment plant production are associated with the off-season production of ornamentals and foods of high value when outdoor production is not possible. In

agriculture sector of India, the energy use pattern for unit production of crops has varied under different agro climatic zones. The use of energy in crop production depends on availability of energy sources in particular region and also on the capacity of the farmers. The reduction, elimination or combination at machinery operation will reduce energy (fuel) input and also may reduce the uses of labor and time (Karale *et al.*, 2008). The energy requirement for cauliflower, cucumber and okra cultivation in Coastal Odisha was assessed, the input energy per unit of cauliflower, cucumber and okra produce was 9.63 MJ kg^{-1} , 2.45 MJ kg^{-1} and 16.67 MJ kg^{-1} , respectively in greenhouse cultivation (Mishra *et al.*, 2012).

Various advantages and benefits of greenhouses

The yield may be 10-12 times higher than that of outdoor cultivation depending upon the type of greenhouse, type of crop and environmental control facilities.

- ✓ Reliability of crop increases under greenhouse cultivation.
- ✓ Ideally suited for vegetables and flower crops.
- ✓ Year round production of floricultural crops.
- ✓ Off-season production of vegetable and fruit crops.
- ✓ Disease-free and genetically superior transplants can be produced continuously.

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- ✓ Efficient utilization of chemicals, pesticides to control pest and diseases.
- ✓ Water requirement of crops very limited and easy to control.
- ✓ Maintenance of stock plants, cultivating grafted plant-lets and micro propagated plant-lets.
- ✓ Hardening of tissue cultured plants.
- ✓ Production of quality produce free of blemishes.
- ✓ Most useful in monitoring and controlling the instability of various ecological system.
- ✓ Modern techniques of Hydroponic (Soil less culture), Aeroponics and Nutrient film techniques are possible only under greenhouse cultivation.

Media used for growing crops

Soil mixes used for greenhouse production of potted plants and cut flowers are highly modified mixtures of soil, organic and inorganic materials. Most greenhouse media contain 30 to 60 percent peat moss alone or in combination with composted pine bark. Other materials are added for drainage and aeration. Various media components that are used are:

Peat: Peat is a main component of most soilless media mixes used today. It is produced by the partial decomposition of plant material under low-oxygen conditions. Differences in peat are related to the climate under which they are produced and the species of plant from which it is formed. Peats from sphagnum mosses have a spongy, fibrous texture, high porosity and water-holding capacity, and a low pH.

Peats formed from sedges are darker, more decomposed and contain more plant nutrients and higher CEC than peat from sphagnum mosses. Peats are classified as light or dark depending on the degree of decomposition. More highly decomposed, dark peats have higher CEC and nutrient content.

Bark: Bark, a byproduct of saw mills, is used extensively in the nursery industry and has a role in greenhouse media as well. It functions to improve aeration and reduce the cost of media. Pine bark is the most widely used bark source. Bark must be aged or composted before use as a media component as it decomposes the material to a point where further slow decomposition as a media component does not tie up nitrogen needed for plant growth.

Coir: The media component coir originates from ground-waste coconut husks. After most of the fibers are removed, the remaining coir, or coir dust, is marketed for media. Chemical and physical properties of the coir are variable, depending largely on the amount of fiber remaining in the material. Particle size ranges from about 0.5 to 2 mm, is greater than 80 percent pore space and air-filled pore space at container capacity is 9 to 13 percent. Coir has a high waterholding capacity, higher than peat in some tests.

Perlite: Perlite is a volcanic rock that is crushed and heated rapidly to a high temperature (1,800F). The material expands to form a 7 white, light-weight aggregate with high pore space. Water-holding capacity is fairly low, as water is retained only on the surface and in the pores between particles.

Perlite is added to media to improve drainage. It is chemically inert with almost no CEC or nutrients, and a neutral pH.

Vermiculite: Vermiculite is a silicate material that is processed much like perlite. Heating causes tremendous expansion of the particles and results in a highly porous lattice structure with good water-retention properties. Vermiculite is available in a number of grades from fine, for seed germination, to coarser grades for use as media amendments. CEC of vermiculite is fairly high (2 - 2.5 meq/100 cc) and pH varies from slightly to very alkaline, depending on the source.

Take precautions in Green House Cultivation

- ✓ Apply correct amount of irrigation water (neither less nor more).
- ✓ Avoid pouring extra water.
- ✓ Maintain proper humidity. High or low humidity enhances pollination problem.
- ✓ Maintain proper temperature inside. High temperature leads to dropping of flowers and thus reduction in yields.
- ✓ Select disease resistant crops.
- ✓ Immediate attention should be given to any kind of disease occurrence in the green house otherwise it spreads very rapidly.
- ✓ Use double door system in the greenhouse.
- ✓ Plant crops with reduced spacings (both plant to plant and row to row) in the green house compared to open field. This will enhance crop yield.
- ✓ Do not enter the greenhouse without work.

Tips for More Income from Green House

- ✓ Always plan for off-season crops.
- ✓ Plan your crop in such a way that your produce should reach the market when there is maximum demand for it.
- ✓ After the first harvest, take the ratoon or plant next crop without wasting time.
- ✓ Reduce plant and row spacing inside the green house and get more yield.
- ✓ Always fully utilize the green house space. Do not keep blank space.
- ✓ Take immediate measures for plant protection whenever problem is traced. It spreads in a short time otherwise.
- ✓ Apply organic manures also in addition to the chemical fertilizers in order to maintain fertility.
- ✓ Solarize the land inside after about six months for about a week in order to make the land free from pests, germs, etc.
- ✓ Follow a proper crop rotation. Avoid mono cropping for long.
- ✓ Take a short term training for green house cultivation before going for commercial crops in green house.

Cost of Green House

Less expensive greenhouse without fan and pad	Rs. 300 to 500 m ⁻²
Medium cost greenhouse with pad and fan system without automation	Rs. 800 to 1100 m ⁻²
Expensive greenhouses with fully automatic	Rs. 2000 to 3500 m ⁻²



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Biogas Production and Its Role as an Alternative Energy Source

Manisha Sahu and Umesh Singh

Introduction

Bio-energy systems can significantly reduce greenhouse gases by decreasing reliance on fossil fuels. Biogas offers a renewable, non-polluting energy source, helping to curb harmful emissions and providing affordable electricity, especially in areas lacking access. By using waste to generate fuel, biogas reduces deforestation, as fewer trees are cut down for firewood, preserving forests and natural ecosystems.

Biogas: Biogas is a gas mixture produced by microorganisms during anaerobic fermentation, where bacteria break down biomass in an oxygen-free environment, generating methane (CH_4), carbon dioxide (CO_2), hydrogen (H_2), and traces of other gases with decomposed material.

Uses of biogas

- ✓ Used as cooking gas
- ✓ Use of biogas as an engine fuel
- ✓ Use of biogas as vehicular fuel
- ✓ Residue can be used as manure
- ✓ Used for lighting, run pump set, can produce electricity

Production of biogas

The process of bio-gas production is anaerobic in nature and takes place in two stages. The two stages have been termed as acid formation stage and methane formation stage. In the acid formation stage,

the bio-degradable complex organic compounds present in the waste materials are acted upon by a group of acid forming bacteria present in the dung. Since the organic acids are the main products in this stage, it is known as acid forming stage. In the second stage, groups of methanogenic bacteria act upon the organic acids to produce methane gas. The obtained biogas is purified by a process called biogas upgrading. Upgrading of biogas is nothing but removing the impurities from the biogas and adding up the pressure. This upgraded purified biogas can be used as fuel for running motor pump etc. When CNG converted internal combustion engine is connected to the biogas unit, then the biogas can be used for producing electricity. Biogas energy can replace other sources of electricity like hydropower, thermal power and nuclear power.

Components Biogas plant: A physical structure designed to carry out anaerobic digestion of organic materials is called “Biogas plant”. Following are the components of biogas plants:

Mixing tank: Cow dung is collected from the shed and mixed with the water in equal proportion (1:1) to make a homogenous mixture (slurry) in the mixing tank.

Feed inlet pipe/tank: The homogenous slurry is let into the digester through this inlet pipe (KVIC biogas plants)/tank (Janta biogas plants).

Manisha Sahu and Umesh Singh

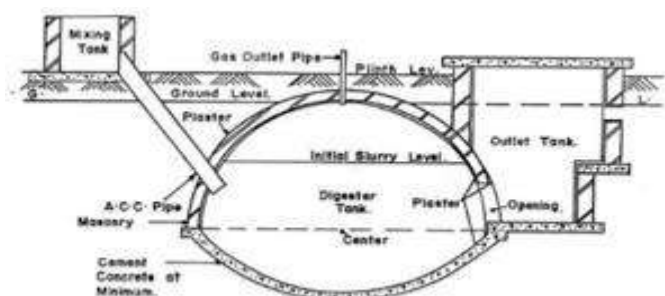
Dau Kalyan Singh CoA&RS, Bhatapara, IGKV, Raipur, Chhattisgarh

Digester: The fed slurry is subjected to anaerobic fermentation with the help of microorganisms inside the digester.

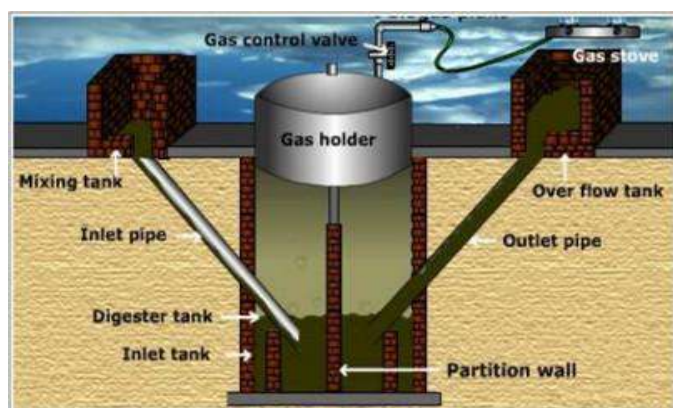
Gas holder: As a result of anaerobic fermentation, gas produced is stored in gas holder (Drum in the case of KVIC and in dome in the case of fixed dome biogas plants).

Slurry outlet tank/pipe: The digested slurry is let out from the digester through slurry outlet pipe (KVIC biogas plants)/tank (Janta biogas plants).

Gas outlet pipe: Stored gas is released and conveyed through the gas outlet pipe present at the top of gas holder.



Deenbandhu or Fixed type Biogas Plant



Floating Drum Biogas Plant

Need for biogas production

Biogas production is important because it can help address many environmental and energy challenges, including:

Reducing greenhouse gas emissions: Biogas can reduce the amount of methane released into the atmosphere from decomposing waste.

Improving air, water, and soil quality: Biogas systems recycle organic waste into renewable energy and soil products, which can improve the quality of these resources.

Providing a renewable energy source: Biogas can be used as a sustainable source of heat and power, and can be used to generate electricity, produce vehicle fuel, and more.

Improving waste management: Biogas systems can help reduce the amount of waste that ends up in landfills.

Recycling nutrients: Biogas systems can recycle nutrients from food waste, reducing the need for fertilizers.

Creating jobs: Biogas systems can create jobs in construction and other related fields.

Challenges of Biogas

Explosive Nature: Biogas is highly explosive, requiring caution during handling. While generating biogas is relatively simple, involving an enclosed chamber without oxygen, storage must be done carefully in open spaces, ideally outside the home, such as on rooftops or in gardens.

Low Energy Density: Compared to LPG, biogas has a lower energy density, meaning more biogas is needed for the same task. For example, a 1 cubic meter biogas digester may only provide around 25 minutes of cooking time, depending on factors like input and environmental conditions.

Difficult Transportation: Transporting biogas is a significant challenge. For commercial use, storing and transporting biogas is complex and expensive, making large-scale applications more difficult.

Conclusion

Biogas is an effective alternative renewable energy source for both rural and urban areas. On average, it saves 144 minutes daily by reducing time spent on fuel collection, cooking, and cleaning. Additionally, it lowers physical stress, improves health, and provides nutrient-rich slurry from biogas plants, which enhances soil fertility and boosts agricultural productivity.

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From Farm to Shelf: How Packaging and Branding can Transform your Agricultural Business

Ajay Kumar Gupta, Suhagni Patel, Mansvi Gour, Somya Nandanwar and Ritika Saini

Harvesting Success

In the competitive world of agriculture, standing out from the crowd is crucial for success. While quality produce is essential, effective packaging and strategic branding can make all the difference in getting your products noticed and loved by consumers. In this article, we'll explore the power of packaging and branding in agriculture and provide practical tips to help you boost your market success.



The Packaging Puzzle: Protecting Your Products and Your Profits

Packaging is more than just a pretty face; it's a critical component of your product's journey from farm to table "a method of enclosing or protecting products for distribution, storage, sale, and use". With one-third of global food production lost or wasted due to improper packaging, getting it right can significantly impact your bottom line.

Types of Packaging Materials

Primary Packaging: Directly holds the product

(e.g., plastic pouches, jute bags, trays).

Secondary Packaging: Groups primary packages (e.g., cartons).

Tertiary Packaging: For bulk transport (e.g., pallets, crates).



The Benefits of Effective Packaging

Reduced spoilage rates: By 20-50% for perishable goods.

Increased consumer convenience: Resealable bags, portion-controlled packaging, and more.

Enhanced brand recognition: Eye-catching packaging that stands out on store shelves

Branding: The Secret Ingredient to Success

A strong brand identity is essential for differentiating your products from competitors and building trust with your target audience. By defining your unique selling proposition (USP), creating a visual identity, and sharing your story, you can create a loyal customer base and drive sales.

The Power of Branding

Increased brand recognition: Consistency in colo-

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rs, fonts, and designs.

Emotional connection: Telling your story and sharing your values.

Customer loyalty: Building trust and loyalty with your target audience.



Steps to Create a Brand

Choose a Name: It should be simple, memorable, and related to your farm or product.

Design a Logo: A symbol that represents your brand values and product.

Maintain Quality: Consistent quality helps build a strong brand reputation.



Tell Your Story: Share your farm's journey, organic practices, or local values to connect with customers

Packaging and Branding in Action

So, how can you apply these principles to your agricultural business? Here are some practical tips to get you started:

Choose the Right Materials: Select materials that offer both protection and appeal. Consider biodegradable materials that resonate with eco-conscious consumers.

Test and Iterate: Before launching your packaging design, test it with your community. Gather feedback on its usability, appearance, and clarity of information.

Utilize Technology: Adopting smart packaging technology, such as QR codes and NFC tags, can provide additional information to consumers and enhance their shopping experience.



Government Support and Certification for Farmers

The Indian government has introduced various schemes to support farmers in branding and packaging their products. These initiatives aim to enhance the quality and competitiveness of agricultural products in both domestic and international markets.

Agri Export Zones (AEZs): AEZs are designated areas where farmers can produce and export agricultural products. The government provides infrastructure, technical support and other facilities to farmers in these zones.



Benefits of AEZs

- ✓ Increased access to international markets.
- ✓ Improved infrastructure and facilities.
- ✓ Technical support and training for farmers.

- ✓ Enhanced competitiveness and quality of products.

PM Formalization of Micro Food Processing Enterprises (PM-FME):

The PM-FME scheme aims to formalize and support micro food processing enterprises.



The government provides financial assistance, technical support, and other facilities to entrepreneurs.

Benefits of PM-FME

- ✓ Financial assistance for setting up and upgrading micro-food processing enterprises.
- ✓ Technical support and training for entrepreneurs.
- ✓ Access to credit and other facilities.
- ✓ Enhanced competitiveness and quality of products.

FSSAI Certification: The Food Safety and Standards Authority of India (FSSAI) certification ensures that food products meet certain safety and quality standards.



Benefits of FSSAI Certification

- ✓ Ensures food safety and quality
- ✓ Enhanced consumer trust and confidence
- ✓ Increased market access and competitiveness
- ✓ Compliance with regulatory requirements

AGMARK Certification: The AGMARK certification is a quality certification for agricultural products. It ensures that products meet certain quality standards and are fit for



human consumption.

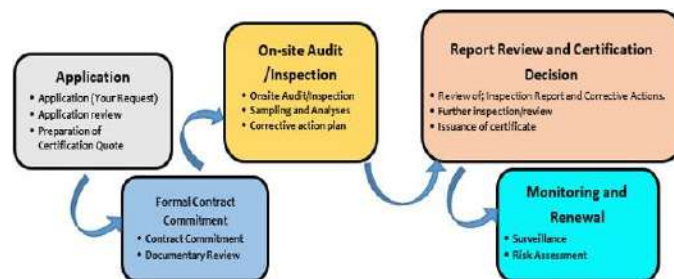
Benefits of AGMARK Certification

- ✓ Ensures quality and safety of agricultural products
- ✓ Enhanced consumer trust and confidence
- ✓ Increased market access and competitiveness
- ✓ Compliance with regulatory requirements

Organic Certification: The organic certification is for organic produce. It ensures that products are produced using organic farming practices and meet certain quality standards.

Benefits of Organic Certification

- ✓ Ensures quality and safety of organic produce
- ✓ Enhanced consumer trust and confidence
- ✓ Increased market access and competitiveness
- ✓ Compliance with regulatory requirements



Conclusion

In the world of agriculture, packaging and branding are no longer optional; they're essential for success. By investing time and resources into designing effective packaging and developing a strong brand identity, you can significantly enhance the marketability of your products, meet consumer demands, and ultimately increase profits.

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Soil Health Monitoring with IoT: A Smart Agriculture Breakthrough

Gaytri Soni

Abstract

The condition of soil directly impacts agricultural productivity, the environment, and food security. Monitoring soil health using traditional approaches is inadequate in the context of climate change, land degradation, and the growing population's food requirements. The Internet of Things (IoT) has granted real-time, exact, and uninterrupted monitoring of soil, revolutionizing soil science and agronomy. IoT connects sensors and cloud systems, which facilitate the accurate measurement of essential soil parameters such as moisture, temperature, pH levels, salinity, and nutrients. This paper discusses the IoT impact on soil health management and its technologies, as well as practical uses, obstacles, future scopes, and innovations in the field.

Introduction

Humanity depends those live systems, and soil is not merely dirt. Healthy soil acts as a water reservoir, nutrient recycler, landlord to organisms, and resilient agricultural systems, but storing and recirculating water requires healthy soil. Assessing soil health through manual sampling, visual inspection, and lab tests is conventional yet limited by time and cost. The intersection of soil IoT technologies has transformed agriculture, especially soil health monitoring IoT technology. Smart sensors capable of collecting and transmitting real-time information enable continuous, remote monitoring of soils. Such technologies enhance the farmers' ability to make informed, timely decisions, improving responsiveness to field variability and ensuring sustainable increases in crop production.

What is IoT-Based Soil Monitoring?

Soil health monitoring utilizing IoT technol-

ogies includes the domain where computers, or the Internet of Things (IoT) are employed to monitor and control soil properties using a network of sensors. These devices collect data, transmitted via wireless low-power technologies, cloud platforms, or mobile applications that allow data to be visualized, stored, and analyzed.

Components and Technologies Involved

Sensors: Capacitive/resistive moisture sensors, ion-selective electrodes, thermistors, pH probes.

Data Transmission: LoRaWAN, Sigfox, NB-IoT, Bluetooth, Wi-Fi

Cloud Platforms: Dashboards, AI/ML Integration, APIs

Mobile Applications: Alerts, control systems, data visualization.

Applications of IoT in Soil Health Monitoring

Moisture Monitoring System: Records moisture to optimize irrigation efficiency.

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Nutrient Detection: Evaluates essential nutrients (N, P, K) for economical fertilizer application.

Soil Chemistry Assessment (pH): Monitors moderate acidity or alkalinity necessary for crop vitality.

Temperature and Salinity Monitoring: Monitors temperature to prevent salt accumulation and adjusts other soil conditions.

Remote Data Acquisition: Realtime monitoring is made possible through wireless sensor networks.

Predictive Analytics: Offering actionable recommendations forecasts the soil conditions using Artificial Intelligence.

Drone and Satellite Data Merging: Enables the mapping of the soil conditions on a greater area.

Benefits of IoT in Soil Monitoring

Effectively managing a farm's irrigation system optimally as a result IoT systems lowers inaccuracies. Specifically, providing timely problem assessment via reliable nutrient and moisture information enables proper decision-making. Furthermore, IoT systems paired with other information technology arms farmers with tools to automate irrigation procedures. These technologies result in improved crop yield, productivity, reduce water and chemicals wastage, and enhance environmental preservation. In addition to these, uninterrupted time monitoring sails soil degradation or imbalance begins enhancing long-term soil health maintenance. Furthermore, lessen human efforts IoT integration boosts operational shelving costs and enhances sustainable agriculture

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Challenges and Limitations

Applying the IoT technology to soil monitoring has a few issues and restrictions even though it offers numerous benefits. First, the technology comes with a wide array of constraints, from setting up the data hosting facilities to the connectivity infrastructure and sensors, which results in a steep initial setup cost that poses a significant hurdle for smallholders and wider farmers. Apart from that, reliable internet access is either impeded or completely absent in the remote rural agricultural regions, which diminishes the impact of real-time monitoring. Moreover, sensor maintenance and calibration are important, as sensor degradation or exposure to harsh weather can spoil calculations. Also, data management requires security as well as risk mitigation because of the enormous data volumes that need safe storage and thorough analysis. Finally, unending ignorance and inadequate training are crucial obstacles that impede the adoption and successful operation of these technologies, requiring unending maintenance to aid them.

Future Outlook

The strongest stimulus of future soils health monitoring IoT systems, electric sensors, artificial intelligence components, and other devices is due to the rapid advances of modern technologies. The impending forecast on IoT adoption is exceedingly strenuous due to the declining device's prices, enhanced energy efficiency, and ease-of-use when

properly operated even by small-and-medium-sized farmers. Furthermore, the conglomeration of IoT interfaces with AI systems and big data analytics will avail accurate prophesies and enable even faster decision processes. The capabilities and reach of IoT systems will be further expanded by emerging technologies like 5G, satellite-based connectivity, and blockchain for secure data sharing. IoT-powered soil monitoring will eventually be essential to precision agriculture, assisting in resource conservation, food security, and mitigating the effects of climate change on farming.

Conclusion

In summary, IoT has become a game-changing instrument for soil health monitoring, providing real-time insights that improve sustainability, resource efficiency, and agricultural productivity. IoT helps farmers make well-informed decisions that maximise crop yield while reducing environmental impact by enabling precise management of soil conditions. Ongoing technological advancements and greater accessibility are opening the door for wider adoption, notwithstanding present obstacles like exorbitant prices, connectivity problems, and the requirement for technical training. IoT will be essential to maintaining the long-term health of soil and the success of sustainable farming methods as agriculture continues to embrace digital innovation.

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Urban Gardening: Future of Farming

Pankaj Kumar Ray

Introduction

Urban gardening refers to growing plants, fruits and vegetables in an urban environment such as a city or town. Small plots, containers, or other types of horticultural methods are used to grow plants in areas not normally used for agriculture. Urban gardening is growing in popularity as more and more people seek to grow their own food, connect with nature and improve the urban environment. Urban gardening also helps build communities by allowing individuals and groups to work together to create shared green spaces and encourage sustainable practices. In recent years, urban farming has become more popular as people have become more interested in locally grown and sustainable food sources.

Urban Farming Scenario in World

The global urban farming market is projected to grow at a CAGR (Compound Annual Growth Rate) of 6.8% from 2021 to 2028. The market is driven by growing demand for fresh, healthy, local produce. In the United States, the number of urban farms increased by 30 between 2008 and 2016, with an estimated 25,000 urban farms operating nationwide. According to a report by the National Sustainable Agriculture Coalition, urban agriculture can deliver a range of social, economic and environmental benefits, including job creation, community

building and improved food security. The COVID-19 pandemic has increased interest in urban farming as people grow their own food and seek self-sufficiency.

Urban Farming Scenario in India

The Ministry of Agriculture and Agricultural Welfare reports that India's urban and suburban agricultural areas are estimated at around 38,000 hectares, producing more than 1.9 million tonnes of food annually. In recent years, urban agriculture has gained popularity in cities such as Mumbai, Delhi, Bangalore and Kolkata, with initiatives ranging from community gardens to rooftop farms. In Bangalore, the government has launched an urban farming promotion program with the goal of creating 1,000 urban farming businesses across the city. In Mumbai, the government has launched a program called 'The Future of Agriculture in Mumbai' to encourage urban agriculture with a focus on rooftop farms and community gardens. Hydroponics and the use of aquaponics are becoming increasingly popular in India, especially in urban areas where space is limited. The National Institute of Urban Affairs reports that there are over 300 hydroponic and hydroponic farms in India. Urban agriculture in India also provides employment opportunities and income for urban residents.

Advantages of Urban Gardening

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Access to Fresh and Healthy Produce: Urban gardening provides access to fresh, healthy produce. These products are often more nutritious than store-bought produce. Growing your own food can also save you money on your grocery bill, which can make it more affordable.

Environmental Benefits: Urban gardening can help alleviate some of the environmental problems facing cities, such as air pollution and the heat island effect. Plants absorb pollutants and help release oxygen into the atmosphere, which can improve air quality. In addition, green spaces help reduce the amount of heat absorbed by urban surfaces. Helps mitigate the urban heat island effect.

Community Building: Urban gardening can be a way to bring people together and build stronger communities. You can provide a space for your neighbors to work together, share knowledge, and socialize.

Educational Opportunities: Urban gardening offers people the opportunity to learn about plant biology, sustainable practices and conservation.

Mental Health Benefits: Gardening has been shown to have mental health benefits, such as reducing stress and anxiety and increasing feelings of well-being.

Food Security: It can help ensure food security by enabling access to fresh vegetables in locations where it is not commonly found.

Sustainable Practices: It may encourage resource conservation and waste reduction strategies like composting and rainwater gathering.

There are Many Crops that are Well-Suited for Urban Gardening, including:

Leafy Greens: Leafy greens like lettuce, kale, and spinach are ideal for urban gardening because they are fast-growing and can be grown in small spaces. They are also rich in nutrients and can be harvested continuously.

Tomatoes: Tomatoes are a popular crop for urban gardening because they can be grown in containers and have a high yield. They are also rich in vitamins and antioxidants.

Herbs: Herbs like basil, cilantro, and parsley are easy to grow and can be used in cooking. They can also be grown in small spaces like windowsills or on a balcony.

Peppers: Peppers are another crop that can be grown in containers and have a high yield. They are also rich in vitamins and antioxidants.

Radishes: Radishes are a fast-growing root vegetable that can be grown in small spaces like containers or raised beds. They are also a good source of vitamin C.

Strawberries: Strawberries are a fruit that can be grown in containers and have a high yield. They are also a good source of vitamin C and antioxidants.

Microgreens: Microgreens are small, edible plants that can be grown indoors and are often used in salads and sandwiches. They are easy to grow and can be harvested in as little as two weeks.

Economic and Environmental Benefits of Urban Gardening

Economic Benefits

Reduced Food Costs: By allowing access to fresh, healthy produce that would otherwise need to be acquired from grocery shops or farmers' markets, urban gardening can help individuals and families lower their food costs.

Income Generation: It can also provide an opportunity for income generation, as excess produce can be sold to neighbours, at farmers' markets, or to local restaurants and cafes.

Employment Opportunities: It can create employment opportunities, particularly in urban areas where unemployment rates are high.

Increased Property Values: Green spaces, including urban gardens, can increase property values in urban areas, which can benefit property owners and the surrounding community.

Environmental Benefits

Reduces Water Consumption: It can be designed to use water efficiently, reducing the amount of water needed for irrigation.

Improves Air Quality: It can improve air quality by capturing pollutants and carbon dioxide, and releasing oxygen into the atmosphere.

Mitigated Heat Island Effect: By lowering the amount of heat absorbed by urban surfaces, it can aid in lessening the urban heat island effect.

Biodiversity: It can promote biodiversity by providing habitat for pollinators and other urban wildlife.

Conclusion

Overall, urban gardening can contribute to a more sustainable and resilient urban environment

while delivering economic benefits to individuals and communities. It provides an opportunity to bring fresh, local produce to urban communities. However, urban agriculture can only be successfully integrated into urban areas if consumers perceive it positively and accept it in their communities.

The Buzz behind Blooms: An Insect Pollination

S. Srinivasnaik, V. Ratnakar and Bharati N. Bhat

Pollination means transfer of pollen from one plant to another plant which aids in fertilization, fruit setting and fruit formation. This pollination is aided by many agents like, wind, water and insects etc. Among the insects, honey bees, flies, moths and butterflies play a great role in pollination of many flowering plants (angiosperms). These angiosperms have not only attractive blooms but also supplement pollen and nectar and few plants exude scents which also attract the insects. The pollination aided by insects commonly called as entomophily. While in the process of licking the nectar from the flowering plants, the pollen adheres to the body parts of the insects, while moving to the other plants, the pollen lands on the stigma and start germinating and finally the fertilization is completed. The insects are responsible for pollinating approximately 75% to 80% of all flowering plant species. Specifically, in agricultural crops, insect pollination contributes to an extent of 70% to 90% of the pollination of major food crops. Among these insects, honey bees alone account for 90% of insect pollination in many cultivated crops. Other important insect pollinators include butterflies, moths, beetles and various species of flies and solitary bees.

Pollinators and pollination

Generally, bees (Honeybee (*Apis mellifera*), Bumblebee (*Bombus* spp.), Carpenter bee (*Xylocopa* spp.), Stingless bee (*Meliponini* tribe), Solitary bees (mason bees, leafcutter bees), butterflies (Monarch butterfly (*Danaus plexippus*), Swallowtail butterfly (*Papilio* spp.), Painted lady (*Vanessa cardui*), moths (Hawk moth (*Manduca sexta*), Yucca moth (*Tegeticula* spp.), Owlet moths (Noctuidae family), beetles (Soldier beetles (*Cantharidae*), Sap beetles (*Nitidulidae*), Scarabs (*Scarabaeidae*), flies (Hoverflies (*Syrphidae*), Bee flies (*Bombyliidae*) others (Wasps (fig wasps, paper wasps) thrips tiny, usually accidental pollinators and ants (Occasional pollinator) acts as pollinators in different crops.

One of the most striking illustration of the dependence of plants upon insects for pollination is afforded by fig. The Smyrna fig is exclusively female and does not produce pollen but the fruits are fleshy and edible. The wild fig called Capri fig, produces plenty of pollen but the fruits are inedible. It is the normal host for the agaonid wasp, *Blastophaga psenes* (L.). The female wasp lays her eggs and the larvae develop in galls at the base of the flowers. The males are wingless, never leaves the host, Capri fig tree and it copulates with the female even while the latter is inside the gall. The female wasp is winged

S. Srinivasnaik and V. Ratnakar

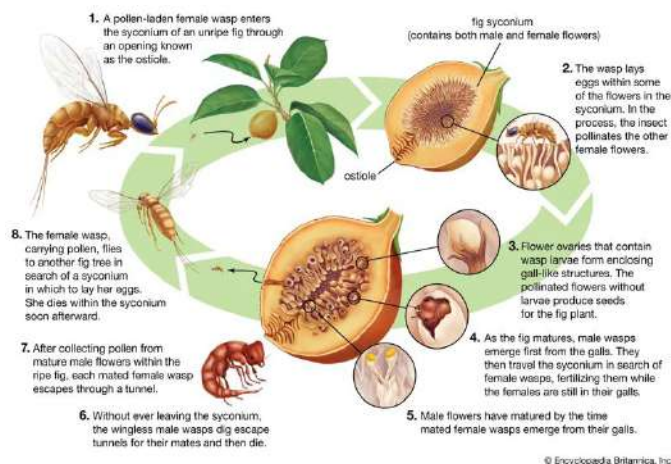
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and escapes the gall in Capri fig and in the process of it exit from the flower gets dusted with pollen. It flies in search of fig flowers for oviposition. When it locates a Smyrna fig flower it deposits pollen on its stigma but it cannot oviposit in it because the ovary is deep seated beyond the reach of its ovipositor in it because the ovary is deep seated beyond the reach of its ovipositor; so only pollination is effected with pollen collected earlier from the Capri fig. Capri fig serves as the normal host for the multiplication and supply of wasps and for supply of pollen. Smyrna fig, not being able to produce pollen itself, depends upon pollen from Capri fig, the transfer of which is efficiently done by the wasp. Therefore the edible Smyrna fig has to be grown side by side with Capri fig, without which the flowers will not be able to produce edible fruits with the characteristic odour and fleshy pulp.

new invasive alien insect pests, change in cropping patterns effect the survival of the pollinators. In order to combat these problems, need to adopt special practices like erection of honey pots, flower gardens in the crops, cultivation of trap crops which yield good quantum of honey and pollen and also shift to eco friendly pest management practices like, usage of botanicals, traps crops, bio pesticides, parasitoids and predators, pheromone traps, root feeding techniques, stem injections techniques, seedling root dip technique, pairing and prolinage, seed treatments etc. can be adopted which are safer to pollinators like honey bees.



Challenges

Intensive agricultural practices, high and repeated application of insecticides, climate change, change in environmental conditions, industrialization, destruction of forests, monoculture, introduction of new and improved hybrids, introduction of

Remote Sensing Approaches for Monitoring Soil Organic Carbon Variability

Ibajanai Kurbah, Sanjeev Kumar and Sushil Kumar Kharia

Soil is the most precious natural resource on the planet, which is important in sustaining agriculture, nurturing ecosystems and controlling the global climate. Soil organic carbon (SOC) is the cause of improving the chemical, physical, and biological properties of soil. SOC is soil organic matter in which carbon is sequestered, and it improves soil structure, fertility, water retention, and microbial processes. It functions as an imperative sink for carbon dioxide in the atmosphere, so it is in demand in fighting climate change. Soil organic carbon has traditionally been assessed by collecting soil samples from diverse sites, transporting them to laboratory facilities, and analyzing those using chemical methods. Although accurate, the procedure consumes a lot of time, requires much money, and is deployable only at limited areas. Therefore, it is difficult to monitor SOC over vast regions, especially in those countries with large agricultural fields. Accurate SOC prediction is vital for efficient carbon management, since SOC is a sensitive carbon cycle parameter whose values can affect CO₂ emissions to the environment profoundly (Paustian *et al.*, 2019). Remote sensing technology, which has

continued to advance over the years, now enables one to estimate SOC rapidly and with ease on very large landscapes. It uses either satellite that image the surface of the earth, measuring the way land scatters sunlight across various wavelengths like visible and near-infrared radiation. The most popular satellites that capture SOC variability as of today are Landsat (Mirchooli *et al.*, 2020), Sentinel-2A (Zepp *et al.*, 2021), and MODIS (Chen *et al.*, 2019). Since soils with more organic carbon are darker and less reflective, scientists could utilize this spectral information to estimate SOC contents without needing extensive physical sampling. Incorporating satellite images, field measurements and mathematical models, high-resolution maps illustrating the spatial distribution of SOC can be developed.

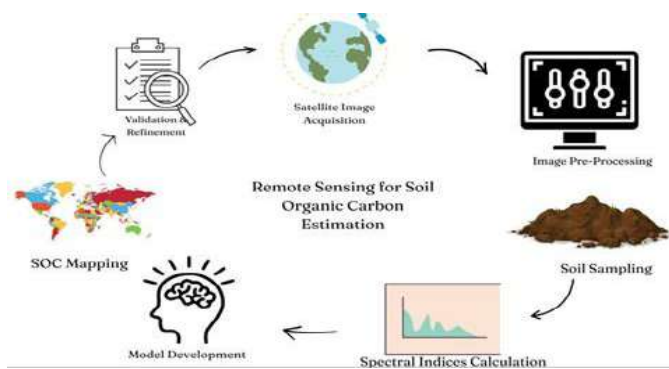


Fig. 1: Remote Sensing for Soil Organic Carbon Estimation

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This approach not only conserves time and resources but also provides valuable information to farmers, researchers, and policymakers that can result in improved soil management, sustainable agriculture, and environmental conservation.

Soil Organic Carbon (SOC): SOC is a term used to indicate the quantity of carbon present in soil organic matter as dead and decomposed remains of plants and animals. A crucial soil health indicator, SOC plays an important role in soil structure improvement, nutrient supply, water retention, and habitat of various microbial communities. Optimal SOC levels result in improved crop yield, enhanced erosion resistance, and sustainable land use. SOC loss, however, is caused by deforestation, intensive agriculture, and global warming and therefore its conservation and estimation become necessary for sustainable agriculture as well as environmental protection.

Traditional Methods of Measuring Soil Organic Carbon: Soil Organic Carbon (SOC) is conventionally determined by the direct sampling of the soil from the field and subsequent laboratory analysis. Some of the most common chemical methods of SOC measurement are the Walkley-Black method (1934), in which organic matter is wet oxidized with the help of potassium dichromate and sulfuric acid, and the dry combustion method, where soil samples are combusted at high temperature in a furnace to determine the carbon dioxide evolved. Even though these methods are recognized for their accuracy and frequent application in scientific

studies, they are time-consuming, costly, and require labour (Omran, 2017). Therefore, scientists have sought alternative ways that can be applied to a variety of conditions as well as different types of soil (Jandl *et al.*, 2014). Ancient soil mapping techniques also face high levels of difficulties in obtaining and managing enormous quantities of sampling points, limiting their use at big scales for carbon mapping and soil monitoring (Ren *et al.*, 2021).

Remote Sensing Helps in Estimating SOC: It offers a contemporary and effective technique to estimate SOC in vast regions without direct soil sampling. Satellites acquire images of the Earth's surface in different wavelengths of light, such as visible, near-infrared (NIR), and shortwave infrared (SWIR). VNIR-SWIR sensors employed in remote sensing follow the concepts of energy-matter interaction (Schwartz *et al.*, 2012). Such soils are generally darker and have higher light absorbance, particularly in the visible part of the spectrum, and these characteristic reflectance signatures can be identified from space. If researchers process specific spectral indices and compare these to field-validated soil measurements, then they can establish prediction models of SOC content at broad landscape levels. This procedure is not just time-saving and inexpensive but can also monitor the soil health in real-time.

SOC Estimation via Remote Sensing: SOC estimation using remote sensing is a sequence of well-coordinated steps that combine satellite imagery, field measurements and statistical model-

ling. The process starts with the collection of high-quality satellite images, typically from satellites such as Sentinel-2 or Landsat, which capture the Earth's surface over a range of spectral bands. Before analysis, to prepare the images, they are pre-processed to remove atmospheric effects and apply precise geometric registrations. Simultaneously, soil samples are collected from various points in the study area and measured in the laboratory for their SOC concentration using methods such as Walkley-Black (1934) or dry combustion. These soil data points play a crucial role in creating prediction models. Spectral indices like the Bare Soil Index (BSI) and Normalized Difference Vegetation Index (NDVI) are then calculated from the satellite imagery to highlight soil characteristics related to organic carbon levels. Statistical or machine learning models e.g., random forests or linear regression are subsequently calibrated using these spectral indices to predict SOC distribution across the landscape. Upon training, these models generate SOC maps that represent varying amounts of organic carbon as colour-coded patches. Finally, model accuracy is validated using independent soil samples, and modifications are incorporated where necessary to improve reliability, and the generated maps provide valuable insights into soil health on a large scale.

Advantages of Using Remote Sensing for SOC Estimation: Application of remote sensing in the estimation of SOC has some benefits compared to conventional approaches. Remote sensing makes it possible to monitor soil condition on a large scale

without resorting to comprehensive field sampling, which can be time-consuming, expensive, and labour-intensive. It makes data collection very fast over huge areas, facilitating real-time or near-real-time determination of SOC levels in large regions. This method also reduces human error and subjectivity that could result from soil sampling manually. Remote sensing further allows continuous spatial monitoring so that changes in SOC over time can be detected, which is important for long-term land use management and mitigation of climate change. It further offers an objective, cost-saving, and non-destructive method to estimate SOC, and as such, is an invaluable asset to precision agriculture, environmental monitoring, and policy making.

Challenges and Limitations: Though remote sensing provides numerous advantages to estimate Soil Organic Carbon (SOC), it does have some challenges and limitations. One of the major challenges is in the detection of SOC in high vegetation or crop cover because plant canopies obscure the soil surface in satellite observation. Cloud cover can also disrupt the quality of images, particularly in the tropics and humid climates. Remote sensing model accuracy relies greatly on ground-truth data quality and quantity, which continue to necessitate field sampling. Soil moisture, surface roughness, and residue cover also have the potential to influence the reflectance signals and contribute to errors in SOC estimation. Sensor types, resolution, and processing methodologies may further complicate cross-study comparisons.

Thus, remote sensing is a very useful tool, and it has to be applied judiciously in combination with field measurements and accurate model calibration to make reliable results possible.

Conclusion

In conclusion, remote sensing has transformed the process of quantifying Soil Organic Carbon (SOC) into an easier, cheaper, and expandable process compared to conventional approaches. Through the application of satellite images and advanced spectral analysis, we can easily and accurately monitor SOC levels across large regions. The technology not only saves time and resources but also provides vital information for land management that is sustainable, precision agriculture, and climate change mitigation. Since the demand for the better monitoring of soil health continues to grow, remote sensing still remains a vital tool in gathering knowledge on soil ecosystems and generating support for environmental conservation and agricultural sustainability.

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Abiotic Stress in Crop Plants: Integrative Insights from Genes to Ecosystems

Sanjeev Kumar, Ibajanai Kurbah, Nitesh Kumar, Garima and Ruchika Devi

Across the globe, farmers continually contend with uncontrollable abiotic stresses such as drought, extreme temperatures, and soil salinity, all of which threaten crop productivity and agricultural sustainability. These abiotic stresses are severe threats to crops and they're increasing with climate change. Abiotic factors can also interfere with crop productivity, lifecycle and survival, health including disease and pest resistance and can disturb or limit the plant's adaptation (Ahmad *et al.*, 2023). Over the course of millions of years, they have developed sophisticated strategies for survival and adaptation. They detect stress at the molecular level, initiate protective processes within their cells, modify growth patterns, and even enter symbiotic relationships with helpful soil microorganisms. These responses occur at numerous scales, from the microscopic changes in gene expression to the observable changes in leaves and roots, and even to interactions within whole ecosystems. Now, it is important to understand these multi-scale stress responses. Researchers are investigating how plants sense stress signals, how they activate internal defences, and how they modify their development to

live under stressful conditions. This understanding enables us to produce harder crop varieties, employ biotechnology to make crops more resilient, and engineer better farming methods suitable for a future world.

Whole-Plant Physiological Responses

Plants respond to a variety of stimuli caused by stress, which can involve unique changes related to the plants development and physiology. In this context, there are many mechanisms such as factors like photosynthesis and gas exchange (Bryant *et al.*, 2021), cell death, re-structuring cell wall composition (Tenhaken, 2014), nutrient translocation (Demidchik, 2015), lipid signalling (Hou *et al.*, 2016), metabolites, proteins (Nakabayashi and Saito, 2015) and analyses of their antioxidant profile (Choudhury *et al.*, 2017) that can be altered during stresses. Confirmed adaptations to controlling factors such as slowed growth, are already directly recognized in plants, by minimizing water use and energy, with smaller leaf size and decreased stem length growth. Concurrently, they also invest more in their root system, growing deeper or wider roots to search for water and nutrients hidden in lower

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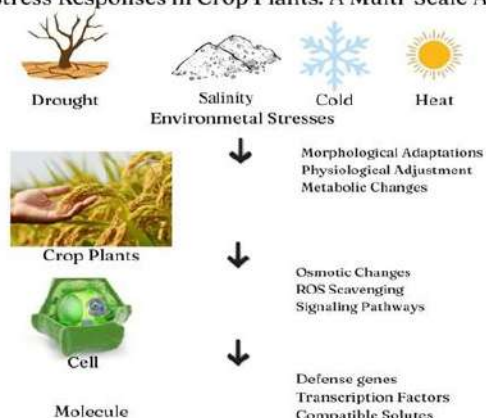
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layers of soil. Leaves also evolve by altering orientation to reduce heat uptake, and by regulating closure of stomata to restrict water loss by transpiration. This, however, may slow down carbon dioxide uptake, and photosynthesis may slow down temporarily. As a reaction to prolonged stress, most plants accelerate their life cycles, quickly advancing to flowering and seed production to gain at least some reproductive success before conditions become too harsh. These whole-plant physiological reactions reflect a fundamental shift in priorities: survival and reproduction rather than growth.

Abiotic Stress Responses in Crop Plants: A Multi-Scale Approach



Ecological and Ecosystem-Level Interactions

Abiotic stress not only affects individual plants but also reshapes relations across whole ecosystems. When crops are exposed to drought, salt, or heat stress, their relations with nearby plants, soil microorganisms, and even pollinators can be dramatically shifted. During water stress, for example, competition for limited soil water is amplified, with stress-tolerant species favoured and the overall biodiversity in fields reduced. Soil microbes also play a role. Helpful microbe's plant growth-promoting rhizobacteria can enhance plant

tolerance by enhancing water and nutrient uptake, regulating stress hormones, and strengthening roots. In return, stressed plants may shift the chemical makeup of their root exudates, which in turn determine what microbes live in the soil around them. Pollination networks may be affected as well. Heat and drought are capable of thinning floral cover and nectar yield, repelling pollinators and stunting plant reproduction. Practices such as soil biodiversity improvement, planting trees (agroforestry), and conserving habitat corridors can reduce crops from the increasing stresses of abiotic stress.

Utilizing Knowledge for Agriculture

Knowledge of how crops react to abiotic stresses at various biological scales has unlocked new pathways for agricultural innovation. Abiotic stress has adverse impacts on plants at all stages of their life cycle especially during plant development and growth (Rai, 2022). Losses in production associated with the many different types of stress account for more than 50% of total losses on 91% of the world's cropping land (Younis *et al.*, 2020). Technologies in precision agriculture like remote sensing, soil moisture sensors, and drone monitoring enable farmers to identify early stress signals and manage water, nutrients, and other inputs more effectively. At the same time, agroecological practices like conservation agriculture and agroforestry strengthen ecosystem resilience organically.

Plant Responses at the Molecular Scale

There are extremely sensitive abiotic sensing and responding mechanisms at the cellular level in

plants. They are specialized membrane-bound receptors that sense changes in the environment outside, i.e., drought or salinity, and induce highly intricate cascades of cellular signals. The molecular mechanism by which plants respond to abiotic stress involves many levels and processes of abiotic stress which may involve sensing, signal transduction, transcription, processing, translation, and protein modification and is a complicated response mechanism involving many genes, signaling pathways, and regulatory metabolic processes (Dong *et al.*, 2022). The abiotic stress hormones abscisic acid (ABA) is quickly produced and induces cascades of abiotic stress-involving genes into changing the physiology of the plant. These genes induced by stress encode proteins that defend against cellular structures, modulate ion channels, and synthesize antioxidants to detoxify toxic molecules.

Conclusion

With the rising frequency and intensity of abiotic stresses driven by climate change, building resilient food systems is now a critical global priority. Understanding plant response, from molecular signalling to whole-ecosystem interactions, gives us a strong basis for developing crops to meet future challenges. Breakthroughs in genetics, biotechnology, and precision agriculture provide promising tools for improving stress tolerance, but ecological and sustainable farming practices are equally essential. The future of agriculture is not merely to endure stress, but to thrive in spite of it.

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Waterleaf is a Neglected and Unattention Leafy Vegetable in India

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Abstract

The Waterleaf (*Talinum fruticosum*) belongs to the family Talinaceae, and it is perennial herb crop. It is also called as Sambar keera, Surinam purslane, Philippine Spinach and Sweet heart etc. It is adopt to all the type of Soil and Climatic conditions. Leaves and stems are edible and it have high nutritive value and presence of some bioactive compounds such as Flavonoids, Alkaloids, Saponins and Tannins. It have some medicinal properties, it is used to cure cardiovascular diseases, Asthma, Diabetes and Cancer. The Waterleaf contain Specific compound such as Squalene. It is a type of Natural lipid. This Squalene used to treating of inflammation injuries, Skin problems and Cancer. This crop is widely cultivated in Mexico, Florida and Africa as leafy vegetables. It can be grown in all regions with low cost of cultivation and don't need special care for production.

Introduction

Green leafy vegetables (GLV) are playing important role in the human health. ICMR advised to consume 50 grams of green leafy vegetables per day. These GLV are provides some amount of Fibers, Vitamins and Minerals (Asaolu *et al.*, 2012). Majorly the leafy vegetables are short duration crop. There are several Phytochemicals are present in leafy vegetables. Excess consumption of GLV cause effect forming stone in Kidney. Protein content present in Green leafy vegetables as cheap and best. The Waterleaf also comes under the category of leafy vegetables. *Talinum fruticosum* (Waterleaf) is a leafy Vegetable. It is originated in Tropical Africa and it is

widely cultivated in Asia, Africa (Nigeria), South and Central America. It belongs to the family Talinaceae (Formerly known as Portulacaceae). Waterleaf is an edible and Perennial Herb crop. It is a self-pollinated crop. In Tamil Nadu Waterleaf is called as Sambar Keera or Sambar Cheera. Some of other names are Sweet heart, Grasse grand pourpier, Surinam purslane, Blatt ginseng, Philippine spinach, Cariru, Javan spinach and Lustrosa Grande. It is easily grown and adapts to any climatic conditions. Waterleaf is grown well in all the type of soil and well grown in low fertile soil also. Water leaf is a short duration (Short life span) crop and it takes about normally 30 to 45 days from planting.

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The Plants grow up to 80 to 90 cm height and the leaves are edible it is soft and succulent in nature. In leaves high nutritive value are present. The plant bears a bright pink color flowers and flowers are in small in size. Some of the regions like Mexico and Florida are majorly grown and consumed as leafy vegetable. It is majorly propagated through both sexual and asexual method i.e., Seeds and Vegetative cuttings. The seeds are in small in size. Waterleaf is used for both Kitchen garden and ornamental garden. Waterleaf is harvested in 28 to 35 days after planting. The leaves and shoots can harvest at interval of weekly once. The harvest can be done up to 2 to 3 months. This article gives an Importance of Medicinal and Phytochemical uses of *Talinum fruticosum* (Waterleaf).



Botanical Description: *Talinum fruticosum* is an Herbaceous Perennial plant species with Bulging root system and Narrow, Trichomeless and fleshy stems. It can grow up to 3 to 5 feet in height. The leaves are cluster in top of the stems. Leaf blades are Spatulate and buldging. The leaves and stems are pale green in color and its surface is smooth. Growth habits for the Waterleaf erect growth, stems is tubular shape (Cylindrical) and narrow at each end. Flowers of the plant are Bright pink in color and it is bisexual. It is Self-pollination crop but cross pollination occur less. Inflorescence for Waterleaf is triangular. After 5 to 8 of flowering the fruit deve-

loped. The fruit ripening occurs after 2 to 3 weeks from flowering and its fruits are pale green in color, Spheroid in shape and each fruit contain more number of seeds. The seeds are Brunette in color.

Propagation: It is Propagated through both Seeds and Vegetative methods i.e., Cuttings. Weight of the 1000 seeds is about 250 mg. But, the seeds have very low germination percentage and poor viability. By vegetative method, it is easy to produce in large amount of Plants. The cuttings should be 10 to 15 cm and it can be directly planted in the main field. It reduces the crop duration and increase yield. So, Propagation by cuttings is a best method compare to using seeds for propagation.



(a) Stem cuttings,

(b) Seeds

Harvesting: Harvesting starts 28 to 35 days after planting. The leaves and shoots harvested at the interval of weekly once. First 3 to 4 harvests give better and more yield. After 4 harvests the yield becomes declined. The harvest can be done by hand or cutting tool. The yield ranges from 50 to 125 tons per hectare. The harvested Leaves and stems are highly perishable and it's dry after 2 hours of harvest. Harvested leaves and stems materials should be stored in plastic bags. Storage temperature of 16.1°C to 18.8°C.

Traditional uses: *Talinum fruticosum* have several

Table 1: Phytochemical composition and mineral composition per 100 g

Constituents	Dry samples Content (mg/100 g)	Wet samples Content (mg/100 g)	Constituents	Content per 100 g
Flavonoids	69.8 ± 4.4	58.3 ± 9.0	Calcium (Ca)	83.1 ± 0.39
Alkaloids	55.5 ± 5.0	13.8 ± 5.0	Magnesium (Mg)	75.8 ± 0.04
Saponins	1.48 ± 0.2	1.37 ± 0.60	Phosphorus (P)	124.9 ± 0.28
Tannins	1.44 ± 0.7	1.10 ± 0.26	Iron (Fe)	3.77 ± 0.1
			Zinc (Zn)	1.52 ± 0.04

medicinal benefits and it is used as medicine for several injuries and diseases by our ancient people. Because of presence antioxidant, anti-inflammatory and anti-cancerous properties in the plants naturally. The medicines are used for curing Asthma, Diabetes, Stroke, Blood pressure and Cancer. The leaves of the plants are harvested at any stages of consumption. Tannins is present in leaves and stems and it is used to curing Ulcers and Wounds. These plants are increase the stamina and acts as an Immune-stimulant agent.

Health benefits: Waterleaf has more health benefits and it contains Squalene content. The Squalene is a type of natural Lipid it found naturally and it contains inflammatory and antioxidant properties and it fight against Cancer. Waterleaf is rich in the source of Iron, α - tocopherols, β - tocopherols, Lipids, Potassium, Essential oils, Calcium, Vitamins and Magnesium. It contains low amount of Hydrocyanic acid content than other leafy Vegetables. It regulates several problems like Heart problems, Asthma, Scabies and Blood pressure (Ogunlesi *et al.*, 2010).

Composition of Bioactive Compounds

It contains some bioactive Compounds these are given in Table 1.

Conclusion

Waterleaf is an important Green leafy vegetable for the Human consumption. Because it contain

several Nutrients and Phytochemical compounds are reported in leaves and stems. Waterleaf can adopt all types of Climatic conditions and soil. It has enormous therapeutic Value. Waterleaf contains a type of natural Lipid i.e., Squalene and this lipid used to cure several problems. Ancient people cultivated more in the old decades. Now days its declined due to lack of awareness about Waterleaf. It has several medicinal properties. The presence of anti-cancerous properties in Waterleaf helps to cure Cancer. So, Researchers should give knowledge about Waterleaf Nutrient importance. Future studies are focused on assessing Nutrient value and Preparing of Value-added products from the Waterleaf.

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Temperature Strees on Rice under Rainfed Conditions and Mitigation by Applying Phytohormones

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Abstract

Rainfed rice systems, crucial to global rice production, are highly susceptible to temperature variability due to their reliance on natural precipitation. Temperature extremes, especially during sensitive developmental stages, can negatively affect rice growth and yield. Recent studies highlight the role of phytohormones in enhancing rice resilience to such stresses. This review examines how temperature stress impacts rainfed rice and discusses the potential of various phytohormones to mitigate these adverse effects.

Introduction

Rice (*Oryza sativa* L.) is a staple for over half the global population. Rainfed lowland and upland rice ecosystems account for about 38% of the world's rice-growing areas (IRRI, 2010). These regions frequently experience unpredictable weather, with extreme temperatures posing a major threat to crop performance. High temperatures during flowering and cold spells during early growth stages significantly impair yield. Phytohormones such as abscisic acid (ABA), salicylic acid (SA), jasmonic acid (JA), among others, have shown potential in enhancing rice's tolerance to such environmental stressors.

Impact of Temperature Stress on Rainfed Rice

Physiological and biochemical effect: Elevated temperatures ($>35^{\circ}\text{C}$) hinder photosynthesis, degrade chlorophyll, and disrupt cell membranes, increasing lipid peroxidation (Wahid *et al.*, 2007).

Conversely, low temperatures ($<15^{\circ}\text{C}$) stunt seedling growth and hinder tillering (Shimono *et al.*, 2007). Both temperature extremes prompt the build-up of reactive oxygen species (ROS), causing oxidative damage unless neutralized by the plant's antioxidant systems.

Effects on Growth and Yield

Temperature stress can lead to:

- ✓ Reduced crop duration
- ✓ Decreased tillering and panicle development
- ✓ Increased sterility in spikelet's
- ✓ Poor grain filling

These effects contribute to significant yield losses, especially where irrigation is not available to moderate the stress (Prasad *et al.*, 2006).

Phytohormones as a Strategy for Stress Alleviation

Phytohormones are key regulators of plant growth and stress responses. When applied external-

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ly, they can boost the plant's defense mechanisms under temperature stress.

Abscissic Acid (ABA): ABA helps conserve water by inducing stomatal closure and activates stress-related gene expression (Zhang *et al.*, 2006).

Salicylic Acid (SA): SA enhances antioxidant enzyme activities (SOD, CAT, APX), reducing oxidative stress caused by high and low temperatures (Khan *et al.*, 2013).

Jasmonic Acid (JA): JA strengthens stress signaling pathways and antioxidant responses, improving plant tolerance to temperature extremes (Wasternack and Hause, 2013).

Cytokinins: These hormones delay leaf aging, maintain chlorophyll levels, and support growth under thermal stress (Rivero *et al.*, 2007).

Brassinosteroids (BRs): BRs aid in cell growth, chlorophyll synthesis, and production of heat shock proteins (Vardhini and Anjum, 2015).

Gibberellic Acid (GA): GA promotes seedling growth under cold conditions by enhancing enzyme activity involved in mobilizing stored nutrients (Iqbal and Ashraf, 2007).

Application Techniques for Rainfed Systems

Seed Priming: Treating seeds with hormone solutions (e.g., 0.5 mM SA or GA₃) boosts early seedling vigor.

Foliar Sprays: Spraying ABA, SA, or JA at booting and flowering stages helps reduce spikelet sterility.

Split Applications: Dividing hormone doses across growth stages ensures continuous support.

Effective application requires careful attent-

ion to dosage, timing, and method to prevent negative side effects.

Field-Based Evidence

- ✓ Foliar spraying of 0.5 mM SA during reproduction increased grain yield by 15-20% under heat stress (Kumar *et al.*, 2017).
- ✓ ABA treatment helped maintain photosynthesis and water status under terminal heat stress (Ali and Ashraf, 2011).
- ✓ JA application increased catalase and peroxidase activity, lowering lipid peroxidation during cold stress (Zhao *et al.*, 2016).

Challenges and Future Outlook

- ✓ High costs and limited supply of phytohormone
- ✓ Lack of site-specific guidelines
- ✓ Risk of phytotoxicity from improper application

Future strategies

- ✓ Developing cost-effective or nano-based hormone formulations
- ✓ Pairing hormone use with climate-resilient rice varieties
- ✓ Enhancing farmer education and technical support

Conclusion

Temperature fluctuations remain a major challenge for rainfed rice cultivation. Phytohormone application offers a promising approach to strengthen rice resilience by modulating key physiological and biochemical pathways. However, to fully harness this potential, more field trials, optimized protocols, and farmer-oriented strategies are needed, particularly in resource-constrained rainfed areas.

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The Root of Success: High Quality Seed Potato Production in Nagaon District

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Abstract

Agriculture is the primary source of income and employment for a large portion of the population, and Assam economic activity is largely driven by agricultural production, so potato in recent years have become an important commercial crop. From the year 2020-24 five protected net houses each with 0.13 ha of land were established temporarily for cultivation of potato clones, potato breeder seeds at different locations viz KVK, Nagaon farm, Bengena Ati, Senchowa and Burhapotia gaon under the APART Project at Nagaon district. The principle of growing different high quality potato seeds under the protected net house is to minimize the loss caused by insect pests like aphids, whitefly etc. and to improve the quality of seeds for establishing a sustainable seed market linkage in Assam. It was observed that the aphid and whitefly population were non significant under the net houses. The farmers have also adopted the good quality seeds. The seed multiplication process have also started and production of potato seeds under low cost insect proof net house made the availability of good quality potato seeds in Assam.

Introduction

Potato has emerged as fourth most important food crop in India after rice, wheat and maize. Indian vegetable basket is incomplete without Potato. It has been observed that during present trend of diversification from cereals to horticultural crops, shifting from wheat/barley cultivation to potato cultivation is economically rewarding owing to comparative advantage of potato over other vegetable crops. Potato cultivation is highly adaptable to a wide variety of farming systems.

With its short vegetative cycle and high yields within 90-100 days, it fits well into double/triple cropping patterns with rice and is also suitable for inter cropping with maize. Potato is one of the major crops in Assam and ranks third in terms of area (1.40 lakh ha⁻¹) after rice and rapeseed mustard being widely cultivated vegetable crops in Assam. But the average state yield is only 7-10 t ha⁻¹ compared to national average of 25.79 t ha⁻¹. Low productivity for many crops in Assam is due to low quality seed/planting materials and slow varietal replacement rates, deteri-

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oration of soil health, depletion of ground water and limited adoption of modern technologies and practices. The annual seed requirement for the entire state is 2.5 lakh tons. Considering that 25% of the seeds is of local land races, still the state imports 1.9 lakh tons of seed from other states at a cost of Rs.800-1000 crore annually.

In Nagaon district alone net area under potato cultivation is 21785 ha with productivity of 7.37 t ha^{-1} . The total production of potato from Nagaon district is 1.602 lakh MT which is very less due to unavailability of good quality seeds. Most of the farmers save the seeds of the local varieties for the next cropping season because of non availability of recommended varieties for which yield/production is getting low. The current seed replacement is very low in Assam i.e. less than 1%. Using seed/potato over several generations is the major constraint faced by farmers in Assam. Hence, producing quality seeds locally is of utmost importance. Production of new high yielding variety seeds under low cost insect proof net houses and increase in cold storage availability will ultimately lead to productivity gain. As the land as well as climate of the state are very suitable for growing potatoes, so there is tremendous scope for seed production in Assam in general and Nagaon district in particular.

Potato seed production: An attempt was made during 2020 to 2024 to cultivate potato breeder seeds and various potato clones in five locations of Nagaon district, Assam viz. KVK, Nagaon farm, Bengena Ati, Senchowa and Burhapotia gaon in protected net

house condition under APART project. In order to uplift the present scenario of potato seed production in the state many Scientists and Experts from International Potato Centre (CIP) in collaboration with Assam Agricultural University and ARIAS society, different works had been done in the state under the project APART. The principle of growing different high quality potato clones under the protected net house is to minimize the loss caused by insect pests like aphids, whitefly *etc.* and to improve the quality of seeds for establishing a sustainable seed market linkage in Assam. A total number of five (5) protected net houses each with 0.13 ha of land were selected for cultivation of potato seeds in Nagaon district. Since the cost of seeds and transportation loss in imported seeds are very high in potato cultivation therefore different strategies and approaches were prepared and implemented through the project for successful establishment of a local seed market in Assam. In KVK Nagaon, planting was done in the early parts of December. Out of five net houses two were established in the KVK, Nagaon campus and rests were in the farmer's field *i.e.* at BengenaAti, Senchowa and Buhapotia gaon having an area of 0.13 ha each. It was a golden opportunity for KVK, Nagaon to cultivate a total number of forty (40) different clones introduced for the first time in Assam in the year 2020-21 along with four varieties of breeder seeds (*i.e.* Kufri Jyoti, K. Chipsona 3, K. Surya and K. Himalini) grown at KVK, Nagaon campus and collected from cold storage of which K. Surya being the short duration variety of 70-90 days.

Out of 40 different clones very interestingly there was 9 colored clones of which clone MP/20-34 observed dark purple color both inside and outside the tuber. Researchers found that this kind of dark purple varieties of potato is highly rich in antioxidant with anti-cancer properties and reduces blood sugar and blood pressure in human body. However, 10 clones were recorded with good quality and yield so far. In the year 2021-22, at KVK Nagaon 27 clones were grown under the net house which were selected from the previous year (forty clones). These clones were grown with four replications each of which HT/19-4 had the highest yield followed by SML/103 & SML/104. The clones were stored in the cold storage to carry out the trial in the next season too. In the year 2022-23, again the trial was conducted with the 27 clones and a replication of the trial is also being carried out in open condition at farmer's field, at Senchowa. In 2023-24, the trial was again conducted and the best varieties were selected.

The second net house, which was also located in the KVK campus, was used for growing 10000 seeds of potato minitubers with the variety K. Jyoti in the year 2020-21. The seeds were then stored in the cold storage. During 2021-22, K. Jyoti which was stored in cold storage was planted in two net houses viz at KVK Nagaon and at farmer's field at Buhapotia gaon. The farmers were very much satisfied with the variety and the seeds were stored in cold storage for next season. In 2022-23, K. Jyoti was planted inside the net house and even in open condition at KVK, Nagaon. Similarly, in farmer's field also K. Jyoti was

planted in open condition for 3 bighas as well as inside the net house. In 2023-24, again it was planted inside the net house for seed multiplication and the rest of the potatoes were sold as seed to the farmers. Whereas, potato variety K. Mohan was planted in the net house located at BengenaAti in the year 2020-21. During 2021-22 at farmer's field, BengenaAti K. Surya and Lady Rosetta (LR) was planted under net house condition where as K. Mohan was planted at open condition. In 2022-23, K. Surya and LR were planted inside the net house and even at open condition. Potato seed multiplication with 10000 seeds of potato variety Yusi Maap was carried out at farmers field, Senchowa inside the net house during 2021-22. Interestingly this potato variety is rich in iron, zinc and vitamin C. The seeds were then stored in cold storage in order to use for the next season. In 2022-23, Yusi Maap was planted inside the net house at Senchowa and 2 bighas were also planted in open condition. Some of the seeds were sold as table potatoes and the rest were kept in cold storage for future use. In 2023-24, again for seed multiplication, the seeds were planted inside net house. In this way the process of seed multiplication had started. It is worthy to be mentioned that all the quality seed materials were arranged and provided by CIP from Potato Technology Centre, Haryana & CPRI, Shimla. However, the planting operations viz. timely monitoring of spraying pesticides, irrigation, scheduled intercultural operations, aphids and pest monitoring etc. were strictly carried out under the supervision of Project Associate, Assistant Project

Scientist and Research Technician of KVK Nagaon. The aphid and whitefly population were recorded non-significant under net houses while early and late blight and potato leaf curl virus infected plants were observed and control measures were taken accordingly.



Few progressive farmers of the district who were getting good production with non-described varieties, got an opportunity to take part actively in two Participatory Varietal Selection (*i.e.* at flowering and harvesting stage) workshops. At flowering stage, farmers were asked to select the plants according to their choice of what they look for in a new variety of potato when the crop is at flowering stage (*eg.* erect plant, plant height, blight resistance, stem thickness etc) and accordingly they casted their votes. In the second PVS workshop *i.e.* at the harvesting stage conducted at KVK, Nagaon, the farmers were asked to select from the different clones based on the best qualities of tubers viz; shape, size, color, low water content, sugar content, high dry mass, shallow eyes, short cooking time *etc.* Organoleptic evaluation was also conducted based on appearance, texture and taste to select the best varieties according to the farmer's preference.

Conclusion

Farmer's positive feedback on adopting various technology demonstrated by CIP, APART shows their interest in expanding their potato growing areas in the coming days. Farmers are very much satisfied with the seed production process as well as with the varieties. Production of potato seeds under low cost insect proof net house will ultimately help farmers to get good quality seeds in Assam since availability of assured quality seed is the most important production constraint in all the potato growing regions of the country.



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A Brief Overview about Gene-Cloning

Bharath and Ranjeet R. Kumar

Abstract

Genes are the basic units of heredity that carry the instructions for how living things grow and function. Gene cloning is a powerful tool used by scientists to study these instructions more closely. It involves making many copies of a specific gene by placing it into a carrier and then growing it inside a simple organism like bacteria. This process helps researchers understand what the gene does and how it affects life. In this article, we provide a simple overview of how gene cloning works, from finding the gene to making sure it has been copied correctly.

Introduction

A gene is the basic unit of heredity, consisting of a specific DNA sequence located on chromosomes which carries the genetic code that directs the synthesis of protein(s) or functional RNA molecules. This code ultimately determines the structure and function of the resulting protein or RNA. Every organism's genome is large and complex, and any specific DNA sequence of interest typically occurs only once or a few times within the entire genome. Furthermore, all DNA sequences are composed of the same four nucleotides [adenine (A), thymine (T), guanine (G), and cytosine (C)] making them chemically identical. Because of this uniformity, standard chemical or biochemical methods cannot easily distinguish or isolate a specific region of the genome. Gene cloning is one of the most important techniques of modern biotechnology and molecular biology that allows the scientists to isolate a specific gene from any organism and insert it into a host organism (generally

a bacterium) using a carrier molecule called a vector. As the host replicates, it also copies the inserted gene, generating millions of identical copies or 'clones' of the original DNA fragment. Cloning a gene enables researchers to determine its nucleotide sequence, explore how it functions within a biological system, and study the protein it encodes. This knowledge is vital in many fields, from understanding genetic diseases to producing insulin, vaccines, and other therapeutics. Over the years, gene cloning has become a routine yet powerful tool in research labs, help us to unlock the secrets of life at the molecular level. This article offers a quick guide to gene cloning, providing a concise overview of the key steps involved from gene isolation and vector insertion to cloning and characterization of the gene.

Key steps involved in gene cloning

Isolation of gene: A gene of interest can be isolated using several methods, including PCR amplification, restriction digestion, Southern blotting, in vitro DNA

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synthesis, cDNA library screening, and gel extraction. Among these, PCR amplification is the most widely used technique due to its high specificity and efficiency. In PCR, the gene of interest is selectively amplified from source DNA such as genomic DNA, cDNA, or plasmid DNA depending on the intended application. The amplified gene is then eluted and used for downstream process called ligation. Primers are one of the essential prerequisites for gene amplification. Primers are short, single-stranded oligonucleotides, typically 17-25 nucleotides long, designed to flank the gene of interest. They are synthesized based on the known sequence of the gene, and their design is guided by specific criteria such as GC content, melting temperature (T_m), and the absence of secondary structures. The optimal annealing temperature of the primers is typically determined using gradient PCR, which helps ensure both specificity and efficiency of amplification. Once the conditions are optimized, the polymerase chain reaction (PCR) is carried out in a standard 50 μ L reaction volume. This reaction mixture includes template DNA, forward and reverse primers, deoxynucleotide triphosphates (dNTPs), a suitable buffer, magnesium chloride ($MgCl_2$), and a thermostable DNA polymerase most commonly Taq polymerase or other high-fidelity enzymes. Then the amplified product is analyzed using 1% agarose gel electrophoresis to verify the presence and size of the expected gene fragment. The correct DNA band, identified under UV illumination, is carefully excised from the gel. It is then purified using a silica

column-based gel extraction kit, which effectively removes contaminants such as unused primers, enzymes, and residual nucleotides. The resulting purified PCR product is now ready for ligation into a suitable cloning vector or for use in further molecular applications.

Ligation into the vector: The isolated gene or DNA fragment is inserted into a vector through a process called ligation. In this process, typically, two parts of the eluted DNA (insert) are mixed with one part of the vector to increase the chances of successful insertion. The reaction is catalyzed by the enzyme DNA ligase, most commonly T_4 DNA ligase, which forms phosphodiester bonds between the DNA strands. The ligation mixture is usually incubated overnight at $4^\circ C$ to enhance the efficiency of the reaction. Vectors act as vehicles for transferring the gene of interest into a host organism. Various types of vectors are used for gene cloning, selected based on the size of the DNA fragment to be inserted and the specific application and the types are mentioned in the Table 1.

One commonly used plasmid vector in cloning experiments is the pGEM-T Easy vector, which contains 3' thymidine (T) overhangs at both ends of its multiple cloning site. These T-overhangs are especially useful for ligating PCR products amplified with A-tailed primers, which leave a single adenine (A) residue at the 3' end. The complementary A-T base pairing between the insert and the vector improves ligation efficiency and facilitates the successful insertion of the gene of interest into the

Table 1: Types of vector used for cloning

Vector type	Insert size range	Description
Plasmid vectors	Up to ~10 Kb	A small, circular DNA molecule commonly used in molecular cloning; replicates independently within bacterial cells and contains essential features such as an origin of replication, a selectable marker (an antibiotic resistance gene), and a multiple cloning site (a region with several unique restriction sites); suitable for cloning small DNA fragments and are also widely used for protein expression.
Bacteriophage λ vectors	10-20 Kb	Lambda phage vectors are derived from the genome of bacteriophage lambda, a virus that specifically infects <i>Escherichia coli</i> (<i>E. coli</i>); They are engineered by removing non-essential viral genes and inserting foreign DNA in their place; widely used for cloning larger DNA fragments than those possible with standard plasmid vectors.
Cosmids	35-45 Kb	Hybrid cloning vectors that combines features of plasmids and bacteriophage lambda; Contains plasmid origin of replication, selectable marker genes and cos sites from lambda phage, which allows the DNA to be packed into phage particles for efficient delivery into <i>E. coli</i> ; it replicates autonomously like plasmids once get inside <i>E. coli</i>
Bacterial Artificial Chromosomes (BAC)	100-300 Kb	BACs are cloning vectors derived from the fertility (F) plasmids of <i>E. coli</i> ; they replicate stably in <i>E. coli</i> as low-copy-number plasmids and contain a replication origin, a selectable marker (such as an antibiotic resistance gene), and a cloning site for the insertion of foreign DNA; commonly used in genomic library construction for cloning large DNA fragments
Yeast Artificial Chromosomes (YAC)	Up to ~1 Mb	YACs are cloning vectors designed to mimic natural yeast chromosomes; Contain essential chromosomal elements such as a centromere (for proper segregation during cell division), telomeres (to protect chromosome ends), an autonomously replicating sequence (ARS) that serves as the origin of replication, and selectable markers for both yeast and bacteria; generally used for cloning extremely large genomic regions and for mapping large eukaryotic genomes.

plasmid.

Transformation into host cells: In molecular cloning, ligation is followed by transformation a crucial step in which recombinant DNA (a vector combined with an inserted DNA fragment) is introduced into a host organism. The most commonly used host in gene cloning is the bacterium *Escherichia coli* (*E. coli*), selected for its ability to rapidly replicate and stably maintain foreign DNA. To facilitate DNA uptake, *E. coli* cells are first made competent, meaning they are treated to enhance their ability to absorb exogenous DNA. One commonly used strain is DH5 α , which is highly efficient for cloning applications. There are two primary methods for making bacterial cells competent:

Chemical transformation: Cells are treated with calcium chloride and then subjected to a brief heat shock at 42 °C, which promotes DNA uptake.

Electroporation: Cells are washed in a salt-free buffer and exposed to a short electric pulse, creating temporary pores in the membrane that allow recombinant DNA to enter. Both methods facilitate the successful uptake of recombinant plasmids into host cells, enabling subsequent selection, replication, and analysis.

Screening and selection of transformed host: After the ligation process where typically three parts of insert DNA are mixed with one part of vector multiple products can form: recombinant vectors (vector plus insert), empty vectors without inserts, and free insert DNA molecules. During transformation, only a fraction of competent *E. coli* cells will take up plasmid DNA. Among these, some cells will receive recombinant plasmids, some will take up empty vectors, and others may not take up any DNA at all.

To identify cells containing recombinant plasmids, selection and screening steps are used. The pGEM-T Easy vector carries an ampicillin resistance gene, allowing only transformed cells to grow on agar plates containing ampicillin. However, antibiotic resistance alone cannot distinguish cells carrying recombinant plasmids from those with empty vectors.

To further differentiate these, blue-white screening is employed. The vector contains the lacZ gene, which encodes the enzyme β -galactosidase. When insert DNA is successfully ligated into the vector, it disrupts the lacZ gene, preventing β -galactosidase production. To detect this, transformed *E. coli* are plated on agar containing ampicillin, IPTG (Isopropyl β -D-1-thiogalactopyranoside, an inducer of the lac operon), and X-gal, a synthetic compound that mimics lactose. Although X-gal is not lactose, it contains a galactose moiety and serves as a substrate for β -galactosidase. When β -galactosidase cleaves X-gal, a blue insoluble compound is produced, causing colonies with functional lacZ to appear blue. Colonies harboring recombinant plasmids with disrupted lacZ cannot cleave X-gal and thus appear white. Therefore, white colonies are selected as they are likely to contain the gene of interest, while blue colonies typically contain empty vectors. This color-based screening efficiently identifies successful recombinants for further analysis.

Cloning: After screening, white colonies of *E. coli* which likely contain the recombinant plasmid are carefully selected and inoculated into LB broth

containing ampicillin, then incubated at 37°C for 12-16 hours. During this period, the bacteria grow and divide, and the plasmid, which carries the gene of interest, replicates independently within each bacterial cell. Because plasmids replicate autonomously from the bacterial chromosome, each cell can harbor multiple copies of the plasmid, effectively amplifying the cloned gene.

Once the culture reaches the logarithmic (log) phase when bacterial cells are metabolically active and dividing rapidly a small volume of the culture is streaked onto LB agar plates containing ampicillin (typically plating about 10^{-3} to 10^{-4} dilutions of the broth culture to isolate single colonies). After an incubation the plates for 12-16 hr, discrete single colonies should appear on the agar surface. An individual colony is then picked and cultured again in liquid LB media with ampicillin and incubated overnight. The following day, the bacterial cells are harvested, and the plasmid DNA is isolated using plasmid purification methods, yielding purified recombinant plasmids ready for downstream applications such as restriction analysis, sequencing, or expression studies.

Evaluation of the gene presence

Evaluating the presence of the gene of interest after successful cloning into the plasmid is a crucial step in confirming the outcome of the gene cloning experiment. Once plasmid DNA is isolated from the transformed *E. coli* cells, the presence of the gene can be verified using one or more of the following methods:

Restriction digestion: This is one of the most common methods used for confirmation. Specific restriction enzymes such as EcoRI or HindIII are used to cut the plasmid at known sites flanking the insertion region. If the gene has been correctly inserted, digestion will produce DNA fragments of predictable sizes, which can then be separated and visualized using agarose gel electrophoresis. The appearance of distinct bands corresponding to both the vector and the insert confirms successful gene cloning.

Colony PCR: In some cases, a faster screening method is employed using colony PCR, where the inserted gene is directly amplified from bacterial colonies without prior plasmid isolation. The presence of an amplification product of the expected size indicates that the colony contains the recombinant plasmid.

Sequencing and *In-silico* characterization: After confirming the presence of the gene of interest, either the isolated plasmid DNA or the master plate containing the transformed bacterial colonies is submitted for DNA sequencing. This step reveals the exact nucleotide sequence of both the vector and the inserted gene, allowing researchers to verify that the correct gene has been successfully cloned. Sequencing methods such as Sanger sequencing commonly used for shorter DNA fragments and next-generation sequencing (NGS) platforms like Illumina sequencing are employed. These technologies provide accurate and detailed sequence data, ensuring the fidelity of the cloned gene and enabling

further analysis or downstream applications. Once the sequence is obtained, it is analyzed through *In-silico* tools to predict the gene's structure, function, coding potential, and other biological features. This bioinformatic characterization helps in understanding the gene's role in the organism and guides further applications, such as gene expression studies, protein production, or functional assays.

Conclusion

Gene cloning is a cornerstone of molecular biology and biotechnology, enabling the isolation and amplification of specific genes for a wide range of applications. Through a series of well-established steps gene isolation, ligation, transformation, screening, evaluation and characterization researchers can not only study genes in detail but also harness them for therapeutic, industrial, and research purposes. As cloning technologies continue to advance in speed, precision, and scalability, their importance in understanding biological processes and developing innovative biotechnological solutions continues to grow.

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Importance of Oleic Acid in Human Diet and Health

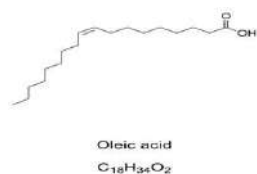
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Abstract

Oleic acid, a prominent monounsaturated fatty acid (MUFA), plays a significant role in promoting human health. Naturally abundant in olive oil, nuts, avocados, and high-oleic oilseed crops, oleic acid has been associated with numerous health benefits. It contributes to cardiovascular protection by improving cholesterol balance, exhibits anti-inflammatory properties, supports brain function, aids in weight management, and may help reduce the risk of certain cancers. As dietary awareness grows, incorporating oleic acid-rich foods into daily meals offers a simple and effective strategy for improving overall wellness. This article explores the nutritional importance of oleic acid, its key dietary sources, and practical ways to include it in a balanced diet.

What is Oleic Acid?

In today's health-conscious world, fats have earned a mixed reputation. While some fats are considered harmful, others are essential for a healthy body. Among the beneficial fats, oleic acid stands out as one of the most important. But what exactly is it? Oleic acid is a monounsaturated fatty acid (MUFA) found naturally in various plant and animal sources. It is the primary component of olive oil, but it's also present in nuts, avocados, and high-oleic oilseed crops such as groundnut (peanut), sunflower, and canola. The name "oleic" comes from "oleum," the Latin word for oil highlighting its oily nature.



Unlike saturated fats, which can raise levels of harmful cholesterol (LDL) or trans fats, which are linked to heart disease, oleic acid is a "heart-healthy" fat. In fact, several studies and dietary guidelines

recommend replacing saturated fats with monounsaturated fats like oleic acid for better health outcomes. As consumers become more aware of the role of nutrition in disease prevention and wellness, understanding the value of oleic acid in the diet is crucial. Let's explore how this unsung hero contributes to a healthier lifestyle.



Fig. 1: Olive oil is one of the richest natural sources of oleic acid

Health Benefits of Oleic Acid

Supports Heart Health: One of the most well-documented benefits of oleic acid is its cardioprotective

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tive role. It helps lower bad LDL cholesterol levels while maintaining or even increasing good HDL cholesterol, reducing the risk of heart attacks and strokes. The Mediterranean diet, known for its high olive oil content (rich in oleic acid), has consistently been associated with reduced cardiovascular disease.



Fig. 2: Image showing cardiovascular health

Reduces Inflammation: Chronic inflammation is linked to numerous health conditions, including arthritis, diabetes, and heart disease. Oleic acid exhibits anti-inflammatory properties, helping to suppress the production of inflammatory markers such as CRP (C-reactive protein). This makes it beneficial not only for heart health but also for autoimmune and inflammatory disorders.

May Help Prevent Cancer: Though research is ongoing, some studies suggest that oleic acid may have anticancer properties. For example, it may help inhibit the expression of certain cancer-related genes and enhance the efficacy of anti-cancer drugs. Diets high in oleic acid have been associated with lower incidences of breast and colon cancers.

Improves Brain Function: Oleic acid is a major component of myelin, the protective sheath around nerves, and is vital for brain development and function. It also plays a role in the production of neurotransmitters.



Some researchers believe that diets rich in oleic acid could help delay or prevent neurodegenerative diseases like Alzheimer's.

Aids in Weight Management: Monounsaturated fats like oleic acid are more satisfying than carbohydrates, leading to increased satiety and reduced overall calorie intake. High-oleic diets have been associated with improved fat metabolism and better body weight control.

Natural Sources of Oleic Acid

Adding oleic acid to your diet doesn't require any complicated nutrition plans. It's naturally present in many common and delicious foods:

Olive Oil: The most concentrated natural source, with over 70% oleic acid.

Avocados: Rich in both oleic acid and fiber, they are excellent for heart and digestive health.

Nuts: Almonds, peanuts, and macadamia nuts are great sources of MUFAs.

High-Oleic Vegetable Oils: These include high-oleic groundnut (peanut), sunflower, safflower, and canola oils. They are often used in cooking and food processing for their stability and health benefits.

Animal Fats: While lesser in quantity, some oleic acid is also found in beef, chicken, and pork fats.



Fig. 3: Oleic acid rich foods

In recent years, plant breeders have develop-

ped high-oleic oilseed crops that produce oil with significantly more oleic acid and less saturated fat. These oils not only provide better shelf stability for processed foods but also improve the nutritional profile of the food supply.

Recommendations and Conclusion

How Much Oleic Acid Do You Need?

While there is no specific dietary recommendation for oleic acid alone, health organizations like the American Heart Association suggest that monounsaturated fats should make up about 15-20% of your total daily calories. For someone eating 2,000 calories a day, that's about 33 to 44 grams of MUFAs, which you can easily get from a combination of oils, nuts, and avocados.

Tips to Boost Oleic Acid Intake

- ✓ Use olive or high-oleic groundnut oil for cooking instead of butter or margarine.
- ✓ Snack on almonds or peanuts rather than chips or sweets.
- ✓ Add avocados to salads, sandwiches, or smoothies.
- ✓ Choose foods labeled "high-oleic" when buying oils or processed snacks.



Fig. 4: Combination of food with healthy fats

The Bottom Line: Oleic acid is not just another fat it's a powerful nutrient with widespread health benefits. From promoting heart health and reducing inflammation to supporting brain function and possibly preventing cancer, this healthy fat plays a

crucial role in a balanced diet. As more research supports its advantages, and as high-oleic crops become more available and affordable, incorporating oleic acid-rich foods into your daily routine is one of the simplest, most effective steps you can take toward lifelong wellness. So the next time you drizzle olive oil on your salad or munch on a handful of almonds, know that you're doing something good for your body thanks to oleic acid.



Fig. 5: Simple meals with oleic acid-rich ingredients can promote long-term wellness

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GIS Based Technologies in Agriculture

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Introduction

In the modern era of spatial intelligence and real-time analytics, Geographic Information Systems (GIS) have emerged as foundational tools for sustainable development and precision agriculture. As global challenges such as food insecurity, land degradation and climate variability intensify, GIS allows us to integrate, analyze and visualize geographically referenced data for better planning, monitoring and management. By transforming raw spatial information into actionable insights, GIS supports smarter decision-making across sectors ranging from environmental management to rural development and agricultural forecasting. Agricultural systems worldwide are facing unprecedented challenges, including climate variability, land degradation and rising food demand. GIS offer a solution by enabling spatial decision-making that enhances productivity while promoting sustainability. GIS is now a key enabler of evidence-based agricultural policymaking, particularly in low and middle income countries (LMICs), where traditional subsistence methods struggle to meet growing demands (Raihan, 2024). The global food demand could rise by nearly 98% by 2050, necessitating more efficient farming strategies where GIS supports this transformation by synthesizing data from multiple domains, soil, weather, crops and topography, into

actionable insights for stakeholders (Elferink and Schierhorn, 2016). Over the past decade, research has emphasized the effectiveness of GIS in streamlining data-driven agricultural planning. Spatial yield modelling employed in Ethiopia to map wheat production gaps, showing how GIS improves both diagnosis and policy targeting (Mann and Warner, 2017). Similarly, use of Landsat-derived indices to estimate crop residue in rice-wheat systems, enhancing sustainability assessments (Memon *et al.*, 2019). Big GIS Analytic framework, a model that utilizes GIS to optimize decision-making across agricultural supply chains was also introduced (Sharma *et al.*, 2018). GIS technologies are increasingly being integrated with Remote Sensing (RS), drones and Internet of Things (IoT) devices to enable real-time monitoring and automation. These innovations enhance the ability to detect crop stress, forecast yields and map controlled environments such as greenhouses, but they also present challenges related to data accessibility, technical expertise and infrastructure particularly in resource-limited settings (Segarra *et al.*, 2020; Al-Ismaili, 2021).

Overview of GIS

GIS is a framework designed to capture, store, analyze and visualize data linked to specific locations on Earth's surface. It combines cartography

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statistical analysis and database technology into a single platform. What makes GIS powerful is its ability to handle spatial (location-based) and non-spatial (attribute) data simultaneously, enabling users to observe patterns and trends that are otherwise hidden in spreadsheets or reports. In agriculture, this means correlating soil health data with crop yield, irrigation needs with rainfall patterns, or pest outbreaks with vegetation stress maps.

Components of GIS: A fully functional GIS system includes the following core components:

1. Hardware	Computers, GPS devices, drones and mobile data collectors
2. Software	Platforms like ArcGIS, QGIS, Google Earth Engine and GRASS GIS
3. Data	Both spatial (e.g., satellite imagery, shapefiles) and non-spatial (e.g., crop type, pH levels)
4. Methods	Analytical approaches and algorithms used to process and interpret spatial data

Functions of GIS: The utility of GIS lies in its diverse functions:

1. Data Input

Collecting data from satellites, UAVs, field surveys and sensors

2. Storage and Management

Organizing large volumes of spatial datasets using geodatabases

3. Manipulation and Editing

Transforming coordinates, projections and correcting data errors

4. Query and Analysis

Asking spatial questions like "Which areas are most drought-prone?" or "What is the average yield by soil type?"

5. Visualization

Generating maps, 3D models and dashboards that communicate findings to stakeholders in an intuitive format

Technology Used in GIS

Modern GIS integrates several advanced technologies to ensure accurate spatial analysis and decision-making:

Remote Sensing (RS): Satellite and drone imagery are used to track land use, detect crop stress and assess environmental changes. These images serve as key inputs for GIS-based analysis.

Global Positioning System (GPS): GPS enables precise geolocation of field data points, making it possible to map and monitor agricultural plots, infrastructure and natural features with high accuracy.

Internet of Things (IoT): Sensors embedded in fields and farm machinery provide real-time data on temperature, humidity, soil moisture and other critical variables, all of which can be spatially visualized and analyzed through GIS platforms.

Data Representation

GIS uses multiple data models to represent real-world phenomena:

Raster: Grid-based format often used for continuous data like satellite imagery, elevation and temperature.

Vector: Uses points, lines and polygons to represent discrete features like roads, rivers and farm boundaries.

Voxel (Volumetric Pixel): A 3D representation that models data within a volume (e.g., soil profiles or underground moisture zones), increasingly useful in environmental and subsurface mapping.

Spatial Analysis Tools: GIS supports complex

operations such as buffer analysis, overlaying maps, spatial interpolation and predictive modeling. These analytical functions allow users to extract deeper insights and model future scenarios with geospatial accuracy.

Applications of GIS in Agriculture

Crop Yield Estimation and Forecasting: GIS has proven effective in integrating remote sensing data with crop growth models to predict agricultural yields. For instance, researchers utilized NDVI and SAVI vegetation indices derived from Landsat satellite imagery to estimate potato yields and found a strong correlation with actual tuber biomass (Al-Gaadi *et al.*, 2016). Another study used MODIS satellite data and GIS tools to simulate wheat yield forecasts in Pakistan, thereby contributing to more reliable early warning systems for food production (Hassan and Goheer, 2021).

Soil Fertility and Land Suitability Mapping: Soil fertility evaluation using GIS has facilitated precision in site-specific nutrient application and land use planning. In Egypt, scientists developed a spatial index based on physical, chemical and biological parameters of soil to assess its fertility and suitability for various crops. Advanced spatial techniques like kriging helped identify variability zones, improving both productivity and environmental sustainability (Abdellatif *et al.*, 2021).

Pest and Disease Surveillance: The integration of GIS with high-resolution satellite imagery allows early detection of pest and disease outbreaks in large agricultural landscapes. A notable example is the

identification of basal stem rot in oil palm plantations through QuickBird satellite data, which enabled spatial targeting of fungicide application and minimized chemical overuse (Santoso *et al.*, 2011).

Drought Risk and Climate Vulnerability Mapping:

GIS facilitates the modeling of drought-prone regions by analyzing climatic, hydrological and land-use data. In one study, a fuzzy logic-based geospatial framework was employed to map drought risk zones, supporting the strategic allocation of water resources and crop diversification efforts in vulnerable areas (Hoque *et al.*, 2021).

Precision Agriculture and Site-Specific Management:

Precision agriculture thrives on spatial intelligence delivered through GIS. Sentinel-2 imagery has been applied to monitor plant stress and guide input use, improving both yield and resource efficiency (Segarra *et al.*, 2020). Another study used drone-acquired imagery and GIS algorithms to detect plantation rows automatically, enabling precise damage assessment and facilitating targeted field interventions (Fareed and Rehman, 2020).

Conclusions

The evolution of GIS from a mapping tool to a comprehensive decision-support system marks a pivotal advancement in the modernization of agriculture. Its ability to seamlessly integrate multiple layers of data, ranging from satellite imagery to in-field sensor readings, enables stakeholders to move from reactive to proactive management strategies. With diverse applications such as land suitability assessment, yield forecasting and precision

input allocation, GIS has redefined how agricultural landscapes are monitored and managed. As digital agriculture scales globally, especially in response to climate and resource challenges, GIS will remain central to enabling location-specific solutions, enhancing efficiency and supporting sustainable development across rural and agri-food systems.

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Citrus Waxing: A Key to Longer Shelf Life

Amrin Fathima, Ramya V. and Adithya V. B.

Introduction

Citrus fruits are perishable in nature. Citrus fruits, including oranges, lemons, limes, and mandarins, are the most widely consumed fruits globally due to their nutrient rich profile. Citrus fruit are susceptible to postharvest deterioration and it declines the quality because of transpiration and respiration that cause water to evaporate after harvest. Fruits has its natural wax layers replaced in the packline to prevent dehydration because they are removed or disturbed during the long washing process (Ahmed *et al.*, 2007). One of the most crucial post-harvest methods for extending fruit's shelf life and preventing undesirable changes is waxing. Waxing of citrus fruit helps to minimize the fruit weight loss and shrinkage, giving the fruit a glossy appearance, and thereby preserving food quality. Additionally, a good wax coating to fruits provides more protection from post-harvest pathological disorders and chilling injuries (Dou, 2004). Emulsion waxes, mainly carnauba and polyethylene coatings, are most commonly used. These wax coatings contribute shine appearance and also maintain gaseous exchange and moisture retention. Polyethylene is a synthetic wax coating with high shine.

It is used as a protective coating in various fruits e.g. oranges, avocados, bananas, mango, pineapples, and vegetables. Carnauba wax is a plant-based wax derived from the leaves of the *Copernicia prunifera* palm tree. Carnauba wax is used to coat candies, chocolates, and fruits (like apples).

Reasoning for Waxing Citrus Fruit

Waxing of citrus fulfils a number of crucial post-harvest handling functions. First and foremost, it aids in minimizing moisture loss by creating a barrier around the fruit there by decreasing water vapour transmission from the fruit to surface. Additionally, application of wax helps in prolonging the shelf-life of the citrus fruit by providing a protective coating which limits the access of environmental elements like oxygen and microbes. And also provides glossy and colorful appearance to the consumers there by increasing its marketability.

Methods of Waxing

Liquid paraffin wax: This technique involves dipping the fruits in heated paraffin. Resins are occasionally applied. After dipping, it creates a thin, transparent coating that provides a glossy surface, slows down oxidation, and aids in moisture retention.

This method is commonly used for apples, citrus

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fruits, and cucumbers.

Slab wax: The process involves pressing the wax up against quickly rotating brushes. However, the efficiency is really low. Solid wax blocks (slab wax) are melted at a controlled temperature before being applied to the product. The ULT (Ultra Low Temperature) process ensures that the wax maintains a consistent viscosity and does not damage the food during application. This technique is frequently applied in industrial settings where sustaining quality requires exact temperature and coating control.

Spray Method: Melted wax is sprayed over the fruit, and then it is mechanically brushed until the necessary thickness of film is achieved. In an appropriate solvent, the wax dissolves. This is dependent on the following: the pressure utilized; the amount of wax used; the temperature of the wax; the distance between the fruit and the spray; and the quantity of spray nozzles. It is suitable for fruits that require a light coating.

Dipping or cold wax method: After washing, fruits and vegetables are dipped into a suitable concentration of wax emulsion without being dried. Prior to packing, they are dried. Purified wax can be heat-sealed and has no taste, smell, or toxicity.

Different Types of Wax

Beeswax: Beeswax One of the most popular animal waxes, which is produced by honeybees. It is prized for its outstanding film-forming qualities, and non-toxicity. It is frequently used in culinary applications as a covering to keep cheese and fruits wet and control microbiological contamination.

Shellac Wax: Shellac wax, which is excreted by the lac bug (*Kerria lacca*), is converted into a resin that is utilized in the coatings. It gives a glossy appearance, moisture-resistant surface, it is commonly used in confectionery.

Candelilla Wax: Candella wax is a hard, brittle substance extracted from the leaves of the *Euphorbia antisiphilitica* plant, which is native to Mexico. It is frequently used as a stabilizing agent in emulsions and as a coating agent for fruits, candies, and chewing gum.

Sugarcane Wax: This wax, which comes from the surface of sugarcane leaves and stalks, is a byproduct of sugar refinement. Fruits and vegetables are coated with it to provide a natural defense against moisture and microorganisms.

Palm wax: Palm wax, which comes from palm oil, is a glossy, crystalline wax that has a high melting point. Because of its smooth smoothness and toughness, it is utilized in food coatings and cosmetics.

Essential Factors in the Waxing Process

In order to preserve the quality and increase the shelf life of fresh products, particularly fruits, waxing is an essential post-harvest procedure. Several crucial guidelines must be adhered to for the procedure to be both safe and effective: Use food grade materials; Rapid drying of the product after waxing on the fruit; Competitive price.

Application

Use of The application of wax coatings is a crucial process in citrus fruit packing houses because

it achieves three goals: (i) giving the fruit the necessary gloss that determines its aesthetic value or appearance; (ii) preventing water loss because the coating partially replaces natural wax that is lost during washing operations and (iii) serving as a vehicle for fungicides, plant growth regulators like 2,4-D, and biocontrol agents. Waxing seems to affect the frequency of postharvest rots in a comparable way. The amount of stem-end rot and internal core rot in citrus fruit treated with several commercial waxes increased *due to Alternaria citri*, *Diplodia natalensis* and *Fusarium spp.* However, green and blue mold and citrus black spot were found to be less likely to form after harvest when a waxing treatment was applied. Moreover, anthracnose is more prevalent in areas with higher concentrations of water wax. The efficiency of different organic acids (ascorbic, benzoic, citric, and sorbic) and salts (potassium sorbate and sodium benzoate) mixed with wax to improve the quality.

Conclusion

Waxing improves product appearance and is an effective method of value addition and preservation for fruits. Citrus fruits are the juiciest among all other fruits. So the waxing coating process is widely used on Citrus fruits. After production of Citrus, Cultivators, Wholesalers, Dealers and sellers adopt the use of Waxes for waxing coating of Citrus. Waxes used on fruits are considered as safe for human consumption. However, governments are supposed to enforce strict measures to ensure some petroleum-based waxes are not used. The producers

are also required to indicate on the label if additional wax has been used to coat the fruit. To be on the safe side as a consumer, thoroughly clean the fruit before eat.

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Medicinal and Aromatic Importance of Spices

R. S. Sarlach, Pallavi Ghosh and Gurvinder Kaur

Abstract

Spices have been used as taste enhancer and have medicinal properties. For instance, garlic is listed as anti-diabetic. It is reported to lower the blood pressure and reduce the blood clotting. It is good for curing cold, flu and ear infection. The use of cumin seed is known to reduce the abdominal gases. According to Yunani Physicians methi seed has a role in slimming down the body, eating salad of methi leaves increases the power of memory. Methi is anti-diabetic and lower blood cholesterol level. Turmeric is very good remedy for arthritis and it lower the blood cholesterol level. Onion is useful in fever. It is applied on irritation of insect bites; scorpion strings and also in skin diseases. Onion cooked with vinegar is very useful in jaundice. Use of onion in summer protects against sunstrokes. Chillies are useful in cosmetics like prickly heat powder and skin ointment. Therefore, this article documents 19 spice species with respect to their medicinal, aromatic and other uses.

Introduction

India is known for cultivation, consumption and export of spices to other countries. According to International Organization for Standardization report, there are about 109 spices grown in different parts of world. India produces 75 spices. Out of these 19 crops have a special significance. In Punjab, chilly, onion, garlic, fenugreek, turmeric, coriander, fennel, dill, jeera, ginger, kolonji, sweet basil, curry leaf tree, Indian mustard, ajwain etc are commonly grown. In fact, practically every farmer grows one or the other crop that can be grouped under spices. However, the quantity of production of these crops is hardly more than their household needs and these crops have not been adopted at commercial level. Spices are used in food to enhance its taste and to give it attractive flavor. Spices have also medicinal properties.

Spices also enhance the keeping quality of food. Some of them are used as preservative in food items. The state of Punjab, at present faces the problem of plenty and there is serious problem of storage and disposal of wheat and paddy. Coupled with this is the problem of continuous depletion of underground water and deteriorating soil health. Therefore, there is an urgent need to shift the land use from wheat-paddy to other crops. Spice crops appear to be a good substitute, though at a smaller scale. In view of this need and usefulness of these crops in daily food requirement of human beings, an effort has been made to introduce these crops to common people through a brief illustrated write up.

Material and methods

Depending upon the routine use of spices, the medicinal and aromatic uses of the spices has been

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scanned to record their medicinal value and present status of availability and occurrence (Anonymous 1992, 1993, Singh *et al.*, 2003, Sarlach and Chohan, 2006).

Results and Discussion

On scanning the literature, a great diversity in spices was recorded. There are about 75 species of spices which are grown in India. There are about 19 varieties of spices grown in Punjab. Therefore, this article documents 19 species of spices with respect to their medicinal, aromatic and other uses which have been described here:

Ajwain (*Trachyspermum ammi*): It belongs to family Apiaceae. It is an annual herb. It is found throughout India. Fruits and roots are useful. Fruits are used as spice, in pickles, confectionery and beverages. Fruits are stimulant, antispasmodic, tonic and carminative and used in dyspepsia and diarrhea and cholera, Roots are used as carminative, diuretic and stomach disorders. Fruits also yield an essential oil which is an aromatic, carminative, antiseptic and expectorant.

Black Pepper (*Piper longum*): It is an herb and belongs to family Piperaceae. Apply black pepper to the skin for measles, nerve pain, itchy skin caused by mites (scabies), and to treat pain. In foods, black pepper and black pepper oil are used as a spice.

Celery (*Apium graveolens*): It belongs to family Apiaceae. It is an annual herb. It requires temperate climate. All parts of this plant are useful. Leaves and stalks are used as salad and sauces, vegetable juices, stews and syrups. Fruits are aromatic and having

pleasant flavor. Seeds are stimulant, carminative, diuretic and tonic in asthma, bronchitis and for liver diseases. Oil is used in flavoring of canned soups, meats, sausages and also used in novel perfume.

Coriander (*Coriandrum sativum*): It belongs to family Apiaceae. It is an annual herb. It is mostly grown in tropical parts. Fruits and leaves are useful. Coriander fruit serves as common flavoring agent for both sweet and savory dishes. Fruits are candied as sugar solution and sold as sugar plum. Fruit is highly aromatic, stimulant, carminative and antispasmodic. Oil is used in medicine, flavoring beverages such as Gin, whiskey. Powder of fried seed is useful in colic of children. Leaves are used for making chutney, flavoring vegetables.

Curry leaf tree (*Murraya koenigii*): It belongs to family Rutaceae. It is a small tree or shrub, and deciduous, It is found in sub Himalayan tracts and adjacent plains. The whole plant is useful. Leaves used as flavoring and in chutneys, yield an essential oil which is used as a fixative for heavy type of soap perfume. Leaves, roots and bark is used as tonic, stomachic and carminative and for diarrhoea, dysentery and for checking vomiting. The juice of root is useful for relief from renal pains.

Fennel (*Foeniculum vulgare*): It belongs to family Apiaceae. It is an annual herb and found in temperate regions. Whole plant is useful. All plant parts are aromatic, and utilized in many ways. Leaf stalk of Florence fennel are blanched and used in vegetable. Seed is used in cooking and for candy and liquor flavoring. Oil is used in perfume, soups and medic-

ines. Fennel seed contains volatile oil and sterols. Volatile oil are used in getting relieve bloating, subside stomach pain, stimulate appetite, diuretic and anti-inflammatory.

Fenugreek (*Trigonella foenum graceum*): It is herbaceous annual legume and belongs to family Fabaceae. Its leaves and seeds are useful. Leaves are consumed as a pot herb and also used as fodder. Seeds are used as condiments. Seeds are aromatic, carminative, tonic and galactagogue. It is also used as poultices for boil and ulcer and given internally as an emollient in intestine inflammation.

Garlic (*Allium satrivum*): It belongs to family Alliaceae. It is a bulbous perennial plant but cultivated as annual. Cloves and leaves of garlic are useful. Bulb of cloves used as spice and condiments. Cloves are also used for flatulence, colic and atonic dyspepsia. Its juice is applied in skin diseases and used as ear drops diluted with water as a vulnerary. It is carminative, gastric stimulant, antiseptic, antibacterial, antibiotic, expectorant, antiuretic, lower blood pressure, reduces blood clotting, expel worms.

Ginger (*Zingiber officinalis L*): It belongs to family Zingiberaceae. It is biennial but stem is annual. It requires warm and humid climate. Ginger rhizome used as a fresh and dried as a condiments. It is used as mix salads and pickles. Dry powder is used in brandy, wine and beer preparation. Rhizome is stimulant, carminative and stomachic, used in dyspepsia, flatulence, colic, vomiting, spasm and painful affection of stomach and bowel.

Indian mustard (*Brassica juncea*): It belongs to family Brassicaceae. It is a tall branching annual herb. Seeds and leaves are useful. Leaves are used as vegetable. Seed oil is used for cooking and flavoring food. Seeds may reduce inflammation, reduce pain, reduce swelling. It may act against cancer, against ulcer and used as an antiseptic. It may act as an antibacterial agent, and may be used against digestive disorders.

Jeera (*Cuminum cyminum*): It is a small, slender glabrous annual herb and belongs to family Apiaceae. It is cultivated throughout India. Its fruits are useful. Fruits are used as condiments in curry powder and flavoring dishes. It contains flavonoids which act as antioxidant. They are carminative, stomachic and astringent, anti-inflammatory, febrifuge, useful in dyspepsia and diarrhea, asthma, cough, bronchitis, ulcer, vomiting and skin diseases. It yields an essential oil used for flavoring liqueurs and cardinal, also in perfumery.

Kolonji (*Nigella sativa*): It is an annual herb and belongs to family Ranunculaceae. Seed is used as spice and condiments and used as a flavoring agent and in medicine as a carminative, stimulant and diuretic. Seed yields an essential oil and used in cough and bronchial asthma.

Mint (*Mentha sylvestris*): Leaves are used as flavoring agent and dry leaves are used as a carminative, stimulant and antiseptic. .it is eaten in the form of chutney. Leaves and flowering tops yield an essential oil which can be used as a substitute of imported peppermint oil for flavoring confectionary.

Onion (*Allium cepa*): It is a bulbous perennial plant but cultivated as annual. It belongs to family Alliaceae. Onion is popular vegetable used for flavoring and pickling. Onion is stimulant, diuretic and expectorant used against flatulence and dysentery. Roasted onion are applied as poultice

Pomegranate (*Punica granatum*): It is a small tree and belongs to family Puniaceae. Its flowers, fruit, seed bark and rind are useful. Flower yields a red dye. Bark and fruit are used for tanning and medicine. Seeds are edible and are used for flavoring food products and making chutney. Bark used to expel tapeworm. Rind is used as an astringent diarrhea and dysentery. Flower buds are used in bronchitis.

Red Chilli (*Capsicum annum*): It is an herbaceous herb and belongs to family Solanaceae. Its fruits are useful. Fruits are carminative and used as a spice. Capsicum preparation are used as counter irritants in lambago, neuregia and rheumatism. Pungent principle is capsaicine.

Sowe/ Dill (*Anethium graveolens*): It is an herb and belongs to family Apiaceae. Fruits and leaves are used as spice and condiments. It yields an essential oil and used as stomachic and diuretic.

Sweet basil (*Ocimum basilicum*): It is an herb or small shrub and belongs to family Lamiaceae. The whole plant is useful. It has been used as a traditional medicinal plant for the treatment of headaches, coughs, diarrhea, constipation, warts, worms, and kidney malfunctions.

Turmeric (*Curcuma longa*): It belongs to family

Zingiberaceae. It is perennial but cultivated as annual. Rhizome of turmeric is useful. Fresh rhizomes are used in salad making. Dry powder is used as a coloring agent and condiments as curry powder. Rhizome contains an essential oil and coloring matter curcumin and essential oil is used as carminative, stomachic and tonic. Turmeric is very good remedy for arthritis and lowers cholesterol level.

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Impact of Agricultural Policies on Food Security

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Abstract

Agricultural policies play a crucial role in shaping food security by influencing food production, availability, access and affordability. These policies include subsidies, trade regulations, price controls, support for farmers land use strategies, investment in agricultural infrastructure and promotion of climate-resilient practices. When well-designed, agricultural policies can enhance food security by promoting sustainable farming, stabilizing markets, improving rural livelihoods, and ensuring that food reaches both rural and urban populations. However, poorly implemented or inequitable policies may lead to inefficiencies, market distortions, environmental degradation, or neglect of smallholder farmers, potentially worsening food insecurity. In the context of climate change, global trade fluctuations, soil depletion, resource scarcity and population growth, the role of agricultural policies has become even more critical. Governments and international bodies must strike a balance between supporting local producers, encouraging innovation, promoting equitable access and maintaining fair, inclusive food distribution systems. This explores how policy decisions impact the long-term stability and resilience of food systems and highlights the importance of inclusive, adaptive and forward-thinking agricultural strategies to ensure sustainable food security for all, especially in vulnerable and low-income communities worldwide.

Introduction

Food security, defined as the ability of all people to access sufficient, safe, and nutritious food at all times, is a critical component of global development and human well-being. Agricultural policies, implemented at national and international levels, play a pivotal role in determining how food is produced, distributed, and consumed. These policies can influence food availability, affordability, and accessibility, which are key pillars of food security. While well-designed agricultural policies can enhance food production, stabilize markets, and protect vulnerable populations, poorly conceived

policies can exacerbate food insecurity, environmental degradation and inequality. This essay explores how agricultural policies affect food security across different regions, analysing both positive and negative outcomes, and highlighting the need for inclusive, sustainable, and climate-resilient policy frameworks in a changing world.

The Role of Agricultural Policies in Enhancing Food Security: Agricultural policies directly influence food production by shaping the incentives, inputs, and infrastructure available to farmers. In many countries, government subsidies for seeds, fertilizer and irrigation have contributed to increased

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crop yields and improved food availability. For example, India's Green Revolution policies in the 1960s and 1970s, which focused on high-yield crop varieties and subsidized inputs, transformed the country from a food-deficient nation to a net exporter of grains. Trade policies also impact food security by determining how countries access international food markets. Liberalized trade policies can improve food availability by allowing countries to import food during domestic shortages. Conversely, export bans and tariffs can lead to price spikes and supply chain disruptions, as seen during the 2007-08 global food crisis, when some major grain-exporting countries restricted exports to protect their domestic markets. In addition, agricultural policies can support food security through investments in rural infrastructure, such as roads, storage facilities, and irrigation systems. These investments reduce post-harvest losses, improve market access for farmers, and enhance the efficiency of food distribution networks. Policy measures that promote research and development in agriculture also lead to innovations in crop breeding, pest control and water management, boosting resilience and productivity.

Subsidies and Their Mixed Impact

While subsidies are often implemented to support farmers and ensure affordable food prices, they can have unintended consequences. In some cases, subsidies distort market incentives, leading to the overproduction of certain crops and underproduction of others. For instance, heavy subsidies for rice and wheat in some developing countries have

led to the neglect of other nutritious and climate-resilient crops like millets and legumes. This not only affects dietary diversity but also reduces ecological sustainability. Moreover, input subsidies such as those for water, fertilizers, and fossil fuels can encourage overuse of natural resources, contributing to soil degradation, water depletion, and greenhouse gas emissions. In the long term, such environmental degradation can undermine agricultural productivity and threaten food security. Reforming subsidies to prioritize sustainability and nutritional outcomes is therefore essential.

Land and Tenure Policies: Secure land tenure is another critical aspect of agricultural policy that affects food security. When farmers, particularly smallholders, have legal rights to the land they cultivate, they are more likely to invest in long-term improvements, such as soil conservation and irrigation infrastructure. Conversely, insecure or informal land tenure can discourage investment, limit access to credit, and increase vulnerability to displacement or land grabs. In many parts of Africa and Asia, land tenure reforms have sought to provide farmers especially women and marginalized groups with legal recognition and protection. These reforms can improve food production and household nutrition by empowering farmers to make decisions that enhance productivity and resilience. However, in practice, implementation challenges, bureaucratic hurdles and gender biases often limit the effectiveness of such policies.

Social Protection and Food Access: Agricultural

policies also intersect with food access through social protection programs. Policies that support food subsidies, public distribution systems, and school feeding programs help ensure that vulnerable populations can afford and access adequate food. For example, Brazil's Zero Hunger Program combined food transfers with support for smallholder farmers, contributing to a significant reduction in hunger and poverty. Conditional cash transfer programs, such as those in Mexico (Prospera) and Ethiopia (Productive Safety Net Programme), link financial support to behaviors like school attendance and health checkups. These programs indirectly improve food security by enhancing household incomes and enabling families to invest in nutritious food. However, the effectiveness of such programs depends on proper targeting, efficient delivery mechanisms, and coordination with agricultural production. If not aligned with local food systems, these programs can create dependency or distort local markets.

Climate-Resilient Agricultural Policies: With climate change intensifying the frequency of droughts, floods, and pests, agricultural policies must now prioritize resilience. Policies that promote climate-smart agriculture such as drought-tolerant crops, agroecological practices, and water-efficient irrigation are essential for protecting food systems against climate shocks. Several countries have introduced national adaptation plans that incorporate agriculture as a key sector. For instance, Kenya's Climate-Smart Agriculture Strategy and India's National Mission on Sustainable Agriculture aim to

build resilience among farmers through capacity-building, insurance schemes and support for diversified farming systems. Incentives for agroforestry, conservation agriculture, and integrated farming systems not only improve productivity but also enhance ecological sustainability. However, the challenge lies in scaling these practices while ensuring that smallholder farmers have access to the necessary knowledge, tools, and financial resources.

Global Agricultural Policy and Food Trade:

International trade policies and global institutions also shape food security outcomes. Organizations like the World Trade Organization (WTO), the Food and Agriculture Organization (FAO), and regional trade agreements influence how countries access global markets and regulate agricultural subsidies. While trade liberalization can increase food availability by enabling the flow of agricultural products across borders, it can also expose small farmers to competition from large-scale producers in other countries. This can lead to the decline of local agricultural systems, especially if domestic policies do not offer adequate support for local producers. Furthermore, food-importing countries can become vulnerable to global price volatility, geopolitical tensions, and supply chain disruptions. The COVID-19 pandemic and the Ukraine-Russia conflict both highlighted the fragility of global food systems and the need for policies that balance openness with self-sufficiency.

Equity and Inclusion in Agricultural Policy:

Equity is a crucial yet often overlooked dimension of

food security. Agricultural policies that fail to consider the needs of marginalized communities such as women, indigenous peoples, and landless labourers can reinforce existing inequalities and leave vulnerable groups behind. Women, who make up a significant portion of the agricultural labour force in many developing countries, often lack access to land, credit, extension services, and decision-making power. Policies that support gender equity through land rights, training, and targeted support can unlock their full potential and contribute to improved food security at the household and community levels. Inclusive policies must also recognize the needs of youth, who represent the future of agriculture. Programs that support youth engagement in agribusiness, innovation, and sustainable farming can address both food security and rural employment challenges.

The Need for Integrated and Participatory Policy

Making: Agricultural policy-making should be inclusive, evidence-based and participatory. Farmers, researchers, civil society, and private sector actors must be involved in shaping policies that reflect local realities and aspirations. Top-down approaches often fail to address the complexities of rural livelihoods and may not gain the trust or cooperation of stakeholders. Integrated policies that bridge agriculture, nutrition, environment, and social protection can lead to more coherent and effective outcomes. The “food systems approach,” which considers the interconnections between food production, processing, distribution, and consumption, is

increasingly recognized as a framework for developing holistic agricultural policies.

Conclusion

Agricultural policies are powerful tools that shape the future of food security. When designed and implemented effectively, these policies can increase food availability, improve access, support farmers, and promote environmental sustainability. However, poorly structured policies can lead to resource depletion, inequality and heightened vulnerability to climate and market shocks. As the global population grows and climate change intensifies, the pressure on food systems will escalate, making it essential for policymakers to adopt forward-thinking, inclusive, and adaptive approaches that prioritize resilience, equity and sustainability. Supporting smallholder farmers, investing in climate-smart agriculture, reforming subsidies, securing land rights, and promoting inclusive governance are all essential components of this transformation. Ultimately, achieving food security in the 21st century will require not just producing more food, but implementing better, smarter policies that are responsive to the evolving needs of people and the planet alike.

Golden Kiwifruit: A Sweet Opportunity for Indian Horticulture

Rupam Nehta, Vishal Rana and Sanjeev Kumar

A Golden Shift from Green

Golden kiwifruit (*Actinidia chinensis*), with its rich yellow flesh, smooth bronze skin, and sweet tropical taste, is rapidly becoming a star in international fruit markets. As India's horticulture sector is looking for higher-value crops to improve the return to farmers and foster better nutritional security, gold kiwifruit represents a golden opportunity indeed. India currently grows green kiwifruit (*A. deliciosa*) in temperate climates in areas, such as Himachal Pradesh, Arunachal Pradesh, Sikkim and Jammu & Kashmir (Jindal *et al.*, 2022). However, golden kiwifruit, which has been developed in New Zealand through selective breeding (Zhong *et al.*, 2012), offers several advantages over green kiwifruit: it is sweeter, less acidic and has a longer shelf life. The golden kiwifruit is packed with beneficial nutrients from vitamin C, antioxidants and actinidin, an enzyme that promotes protein digestion (Kaur *et al.*, 2022; Mishra *et al.*, 2023) and it is ideally suited to the rapidly expanding market for functional foods, not least among urban Indian consumers.

Top Global Varieties

Golden kiwifruit is not a one-size-fits-all crop. Over the years, researchers and breeders have

developed a number of cultivars to suit different climates and market demands:

SunGold™ (Zesy002): A favorite globally, known for high yields and disease resistance (Zhong *et al.*, 2012).

Dori (AC1536): An Italian variety with early ripening and intense yellow flesh.

Jintao & Jinyan: Compact, productive Chinese cultivars rich in vitamin C (Asadi *et al.*, 2024).

Soreli: Early-ripening with high yield potential and excellent flavor.

These cultivars offer a menu of options for Indian farmers to choose from, based on regional conditions.

Nutritional Goldmine: Golden kiwi isn't just a tasty snack, it's a nutritional powerhouse. Here's what makes it shine:

Nutrient	Quantity (per 100 g)	Benefit
Vitamin C	160-200 mg	Boosts immunity and antioxidant activity (Mishra <i>et al.</i> , 2023)
Potassium	300-315 mg	Supports heart and muscle function (Zhang <i>et al.</i> , 2020)
Fiber	2.5-3.0 g	Enhances digestion and gut health (Zhang <i>et al.</i> , 2020)
Vitamin E	1.5-2.0 mg	Improves skin and immune response (Moysidou <i>et al.</i> , 2024)
Actinidin	Present	Helps digest protein-rich meals (Kaur <i>et al.</i> , 2022)

Despite being sweet, golden kiwi has a low

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glycemic index, making it safe for people with elevated blood sugar (Inoue *et al.*, 2021).



Fruits of Yellow flesh kiwifruit

Where can it grow in India?

The kiwifruit thrives mostly at higher elevations between 3,000 and 5,500 feet above sea level in cool, frost-free areas. Kiwifruit needs approximately 600 - 800 chilling hours over the winter months and frost protection in spring as well as protection from certain summer winds. The ideal soil types are well-drained sandy loam soils that are organically-rich with pH slightly acid (5.5 to 6.5). While *A. chinensis* (golden kiwi) thrives in climatic conditions similar to green-fleshed varieties, it may require more careful management under certain environmental stresses. The states already producing green kiwi can act as pilot states for producing new varieties of the golden kiwi.

India's Growing Appetite

India produces approximately 16,000 metric tonnes of kiwifruit each year from approximately 5,000 hectares, which is insufficient to meet domestic demand (Sawant *et al.*, 2023). Today, India seems to import over 75% of its kiwi from New

Zealand, Italy, Iran and Chile (Sharma *et al.*, 2022). As this global import bill continues to grow, it uncovers a major gap and an opportunity. By developing a domestic industry for yellow-fleshed kiwifruit the country can reduce its reliance on imports as well as add new revenue streams for enterprising farmers.

What's needed to succeed

For golden kiwifruit to thrive in India, we need more than just good soil and sunshine:

- ✓ Region-specific field trials to identify the best-suited cultivars.
- ✓ High-quality nursery development for reliable planting material.
- ✓ Farmer training in trellising, irrigation, pruning and nutrition management.
- ✓ Cold-chain infrastructure to preserve fruit quality and extend shelf life.
- ✓ Public-private partnerships to bridge research, innovation, and market access.

The Road Ahead

Golden kiwifruit is not simply a new type of fruit - it is a new front. With its premium benefits, food and nutrition value, and assist in enhancing the market prospects, it can play a big part in reinventing Indian horticulture. By investing in value chains and supporting high potential local growers, India can satisfy an ever-growing consumer base, create higher rural incomes, and diversify its fruit basket with a new aspect of gold.

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Natural Colorants from Bacteria: A Bio-based Alternative to Synthetic Dyes

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Abstract

The growing environmental and health concerns associated with synthetic dyes have prompted the search for sustainable alternatives in the textile, food, cosmetic and pharmaceutical industries. Natural colorants derived from bacteria represent a promising bio-based solution, offering advantages such as biodegradability, lower toxicity and renewable production. This review explores the diversity of pigment-producing bacterial strains, the chemical nature and functionality of their colorants and the cultivation strategies to optimize pigment yield. It also discusses current technological advances, regulatory challenges and the economic feasibility of large-scale bacterial pigment production. Emphasis is placed on the potential of bacterial pigments such as prodigiosin, violacein and carotenoids to replace synthetic dyes, thereby promoting a circular bioeconomy. By integrating microbiological innovation with sustainable practices, bacterial colorants could play a pivotal role in reducing the ecological footprint of dye-intensive industries.

Introduction

Synthetic dyes have played a vital role in the development of modern industries, particularly in textiles, cosmetics, food and pharmaceuticals. However, their widespread use has raised significant environmental and health concerns due to their toxic chemical composition, non-biodegradability and the harmful byproducts released during manufacturing and disposal. Many synthetic dyes are derived from petrochemical sources and involve processes that generate carcinogenic and mutagenic substances, contaminating water bodies and soil ecosystems.

In response to these challenges, there is growing interest in exploring sustainable and eco-friendly alternatives. Among the various sources of natural pigments plants, fungi and algae bacteria have emerged as a particularly promising option. Bacterial pigments are secondary metabolites with vivid hues, diverse chemical structures and bioactive properties. These microorganisms can be cultivated under controlled conditions using inexpensive substrates, allowing scalable and renewable pigment production without relying on arable land or seasonal constraints.

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This article explores the potential of natural colorants from bacteria as a bio-based alternative to synthetic dyes. It discusses the types of pigments produced by bacteria, their functional properties, applications across different industries and the advantages they offer in terms of sustainability and safety. With advances in biotechnology and microbial engineering, bacterial pigments could become a cornerstone in the transition toward greener industrial practices.

Bacterial Pigments: Due to their rapid growth and ease of genetic manipulation, bacteria present a viable and sustainable alternative to synthetic pigment production. These microorganisms not only offer an environmentally friendly option but also demonstrate excellent biodegradability and compatibility with natural ecosystems. Although fungal pigments have seen wider commercial adoption, bacterial pigment production remains largely at the experimental and development stage. Nevertheless, bacteria are capable of generating a wide spectrum of bio-pigments, including melanin, carotenoids, pyocyanin, bacteriochlorophylls, violacein, prodigiosin and monascins. Among these, carotenoids are the most extensively researched due to their vibrant colors and potential industrial value.



Bacterial Pigments

Bacteria that produce pigments can be found in a variety of ecological niches. They are widespread in aquatic and terrestrial environments and have also been identified in extreme habitats such as deserts, salt-affected areas and polluted industrial sites. Moreover, these bacteria have been isolated from organic waste materials like decaying fruits and vegetables, landfill matter, industrial discharge, plant tissues (as endophytes) and even dried seafood. Some of the notable genera known for high pigment productivity include *Achromobacter*, *Serratia*, *Sarcina*, *Thiobacillus* and *Bacillus*. The phylum Actinobacteria contains many pigment-producing species, with several genera being especially prolific. These include *Streptomyces*, *Nocardia*, *Micromonospora*, *Thermomonospora*, *Actinoplanes*, *Microbispora*, *Streptosporangium*, *Actinomadura*, *Rhodococcus* and *Kitasatospora*. Among them, the *Streptomyces* genus is particularly noteworthy for its ability to produce a diverse range of pigments in various hues. Species such as *Streptomyces shaanxiensis*, *Streptomyces griseoviridis* and *Streptomyces coelicolor* are well-documented for their pigment synthesis, with potential applications spanning industries like pharmaceuticals, textiles, cosmetics and food.

Types of Bacterial Pigments

Bacterial pigments are secondary metabolites produced by microorganisms, often serving protective or signalling roles. Common bacterial pigments include:

Carotenoids: Carotenoids are a major class of natur-

ally occurring pigments that are commonly present in both plants and microorganisms. These compounds are lipid-soluble, exhibit colors ranging from yellow to orange to red and are structurally classified as isoprenoid polyenes. They are produced by bacteria such as *Streptomyces coelicolor* and *Arthrobacter sp.*

Violacein: Violacein is a violet to purple pigment that is insoluble in water and was originally identified in *Chromobacterium violaceum*, with the first isolation reported from the Amazon River region in Brazil. This pigment is also produced by bacteria inhabiting a variety of environments. Research has demonstrated that violacein exhibits a range of biological activities, including anti-microbial, anticancer, antiviral and anti-ulcer properties. It is produced by bacteria like *Chromobacterium violaceum* and *Janthinobacterium lividum*.

Prodigiosin: Prodigiosin is a red pigment and a secondary metabolite characterized by a linear tripyrrole structure. It was initially isolated from the bacterium *Serratia marcescens*. This compound is light-sensitive and does not dissolve in water, but it is soluble in organic solvents such as methanol, chloroform and acetonitrile. In natural settings, prodigiosin production typically occurs during the later phases of bacterial growth. It is produced by bacteria such as *Serratia marcescens* and *Streptomyces*.

Melanins: Melanin is a naturally occurring dark pigment that forms through the polymerization of

phenolic and/or indolic compounds. Based on their structure and color, melanins are generally categorized into three main types: eumelanins, which appear black or brown; pheomelanins, which are red or yellow; and allomelanins, which range from dark brown to black. This pigment is commonly found across a wide range of organisms, including animals, plants and various microorganisms.

Table 1: Different Bacterial pigments, their sources, colour and Application

Pigment	Source	Color	Application
Violacein	<i>Pseudomonas aeruginosa</i> ATCC 27852	Purple	Textile dyeing Cosmetics additives Antimicrobial agent Medicine
	<i>Janthinobacterium</i> sp. B9-8		
	<i>Collimonas</i> sp. CT		
	<i>Duganella</i> sp. B2		
	<i>Mazella antarctica</i> P8398 ²		
Indigoidine	<i>Chromobacterium violaceum</i> ATCC 12472	Indigo	Textile dyeing Antimicrobial agent Bio-indicators
	<i>Pseudomonas putida</i> KT2440		
	<i>Corynebacterium glutamicum</i> ATCC 13032		
	<i>Clavibacter michiganensis</i> subsp. <i>insidiosus</i> ATCC 10253		
	<i>Vogesella</i> sp. EB		
Melanin	<i>Epibacterium ulvae</i> U95 ²	Dark/ Brown	Biomedical aspects Antimicrobial agent Bio-indicators
	<i>Dickeya</i> sp. MS2		
	<i>Pseudomonas stutzeri</i> BTCC210		
	<i>Bacillus thuringiensis</i> L-7601		
	<i>Streptomyces</i> sp. ZL-24		
Carotenoid	<i>Bacillus licheniformis</i> MAL	Red/ Orange	Nutritious supplement Bio-indicators Food additives
	<i>Rhodospirillum rubrum</i> S1		
	<i>Rhodospirillum rubrum</i> S1		
	<i>Rhodospirillum rubrum</i> S1		
	<i>Rhodospirillum rubrum</i> S1		
Prodigiosin	<i>Vibrio ruber</i> DSM 14379	Red	Textile dyeing Food additives Antimicrobial agent
	<i>Halobacterium salinarum</i> NRC-1		
	<i>Serratia marcescens</i> NMCC-46		
	<i>Serratia marcescens</i> TKU011		
	<i>Serratia marcescens</i> TKU011		
Rhodopsin	<i>Halobacterium salinarum</i> NRC-1	Pink	Medicine
	<i>Geodermatophilus dictyosporus</i> DSM 43161		
	<i>Geodermatophilus pulveris</i> DSM 46839 ²		

Advantages of Bacterial Pigments

Bacterial pigments offer several advantages over synthetic dyes:

Biodegradability: Unlike synthetic dyes, bacterial pigments are biodegradable, reducing environmental pollution.

Non-toxicity: Bacterial pigments are generally non-toxic, posing fewer health risks to humans and animals.

Renewability: Bacterial pigments can be produced using renewable resources, making them sustainable alternatives.

Diverse Properties: Bacterial pigments possess

various bioactive properties, including antioxidant, antimicrobial and anticancer activities, enhancing their value in multiple applications.

Challenges and Future Prospects

Despite their potential, the commercial utilization of bacterial pigments faces challenges:

Production Costs: The cost of producing bacterial pigments can be higher than synthetic dyes, limiting their widespread adoption.

Stability: Some bacterial pigments may have limited stability under certain conditions, affecting their shelf life and performance.

Regulatory Approval: Obtaining regulatory approval for the use of bacterial pigments in food, cosmetics and pharmaceuticals can be a lengthy and complex process.

Future research focuses on optimizing production processes, enhancing pigment stability and exploring novel applications to overcome these challenges and promote the use of bacterial pigments as sustainable alternatives to synthetic dyes.

Conclusion

Bacterial pigments represent a promising bio-based alternative to synthetic dyes, offering environmental, health and economic benefits. Their diverse applications across various industries underscore their potential in promoting sustainable practices. Continued research and development are essential to address existing challenges and fully realize the potential of bacterial pigments in replacing synthetic dyes.

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Coriander's Global Journey: From Farm to Market

Kinshuk Sharma

Introduction

Coriander (*Coriandrum sativum* L.) is one of the most widely cultivated plants for its seeds. Although some sources may use the terms “seed” and “fruit” interchangeably, the correct term is “fruit,” as these contain the plant's active compounds. Coriander plays an important role in traditional medicine and culinary practices across various cultures, including Ayurvedic, Arabic, Chinese, Latin, and South American traditions. It is commonly used as a spice in curries and meat dishes and as an herbal remedy for various ailments.



Coriander leaves

Coriander seeds

Coriander in full bloom

In ancient Rome, coriander was highly valued, appearing in 18% of the recipes found in “Apicius,” a Roman cookbook from the fifth century. Both the leaves and fruits were utilized, and the demand was so high that coriander was cultivated extensively in Egypt and other regions to satisfy the needs of the Roman market. Coriander (*Coriandrum sativum* L.) is one of the most widely cultivated plants for its seeds. Although some sources may use the terms “seed” and “fruit” interchangeably, the correct term is “fruit,” as these contain the plant's

active compounds. Coriander plays an important role in traditional medicine and culinary practices across various cultures, including Ayurvedic, Arabic, Chinese, Latin, and South American traditions. It is commonly used as a spice in curries and meat dishes, as well as an herbal remedy for various ailments. Coriander is a significant spice crop known for its role in flavoring food. It is a small, bushy herb that typically grows to a height of 25 to 50 cm and features many branches and umbels. The plant has alternate, compound leaves and emits a pleasant aroma. Its flowers are arranged in a compound umbel, which consists of five smaller umbels. The fruit is globular, measuring 3 to 4 mm in diameter, and when pressed, it breaks into two locules, each containing one seed. The fruit emits a delicate fragrance, and the seeds range in color from pale white to light brown. There are two distinct morphological types of coriander: one type is erect and tall with a relatively strong main shoot, while the other type is bushy, with a weaker main shoot and longer, spreading branches. Coriander provides numerous benefits, including powerful antioxidant properties that contribute to anti-inflammatory effects, which can help alleviate different types of pain. Additionally, the unique enzymes present in coriander seeds and extracts assist in lowering blood sugar levels. One of the most significant advantages

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of adding coriander to your diet is its ability to boost immunity, helping your body combat diseases and supporting overall well-being.

Table 1: Nutritional Content in Coriander

Nutrients	Coriander Leaves	Coriander Seeds
Fibre	4.66 g	44.8 g
Carbohydrate	1.9 g	12.9 g
Iron	5.3 mg	17.6 mg
Calcium	146 mg	718 mg
Magnesium	72.6 mg	343 mg
Potassium	546 mg	1473 mg

Coriander is a significant spice crop known for its role in flavoring food. It is a small, bushy herb that typically grows to a height of 25 to 50 cm and features many branches and umbels. The plant has alternate, compound leaves and emits a pleasant aroma. Its flowers are arranged in a compound umbel, which consists of five smaller umbels. The fruit is globular, measuring 3 to 4 mm in diameter, and when pressed, it breaks into two locules, each containing one seed. The fruit emits a delicate fragrance, and the seeds range in colour from pale white to light brown. There are two distinct morphological types of coriander: one type is erect and tall with a relatively strong main shoot, while the other type is bushy, with a weaker main shoot and longer, spreading branches. India is the leading producer of coriander and a significant exporter on the global stage. Other notable coriander-producing countries include Morocco, Russia, Bulgaria, Mexico, Argentina, China, Romania, Japan, and Italy. In India, the main regions for coriander cultivation are Rajasthan, Madhya Pradesh, Andhra Pradesh, Tamil Nadu, Odisha, Uttar Pradesh, and Uttarakhand. Rajasthan stands out as the top state,

contributing nearly 60% of the country's total area and production of coriander. In 2023, Madhya Pradesh produced 396,000 metric tonnes of coriander seeds. The town of Kumbhraj in Madhya Pradesh is the state's second-largest producer, known for its high yield, attracting global companies such as Tata that source coriander seeds from the area. India exported 97.7 million kg of coriander in the 2023-24 period, which was valued at approximately US\$95.9 million. From March 2023 to February 2024, a total of 3,180 cargoes of coriander were shipped from India. In this timeframe, 622 Indian exporters supplied these products to 1,223 consumers, marking a 38% increase compared to the previous year. India exports coriander in various forms, including oil, powder, splits, and whole seeds. In the international market, Indian coriander is valued at \$950 to \$970 per metric tonne. The growth of coriander exports from India can be attributed to several factors, including improved profit margins and supportive policies from the Indian government, such as trade privileges, incentives, and subsidies. Additionally, global exports offer extensive networking opportunities.

The key export destinations for Indian coriander, along with their respective values, are outlined below:

Top India's Coriander importing countries	Export value
China	\$35.29 million
Malaysia	\$14.65 million
United Arab Emirates	\$8.76 million
Saudi Arabia	\$4.59 million
Nepal	\$4.35 million
Egypt	\$3.33 million

Careful planning and targeting the right audience through proper data are essential for making informed export decisions from India. Exporters of coriander seeds in India must be registered with a recognized corporation and provide proper documentation, including a health certificate, FSSAI license, certificate of origin, packing list, APEDA registration, commercial invoice, and packing list. The final step involves identifying potential buyers. The food industry is the largest consumer of coriander, as the herb is used in cuisines across Asia, the Middle East, and Latin America. Coriander leaves are commonly used as a garnish or in salads, while the seeds serve as a spice in curries and pickles. The production, trade, and consumption of coriander are expected to grow in the coming years, driven by increasing demand for the herb in various sectors. As consumers become more health-conscious, the use of coriander in food and pharmaceutical products is anticipated to rise.

In conclusion, coriander is a versatile herb with a wide range of uses in the global market. Its production, trade, and consumption are key components of the industry, which is poised for future growth.

Broad Bed Furrow (BBF) Technology: A Solution for Soil Conservation, Water Management and Yield Improvement

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Abstract

Climate change is increasingly disrupting global agriculture, resulting in rising temperatures, unpredictable rainfall, and more frequent extreme weather events. These shifts pose significant threats to the livelihoods of millions of farmers, particularly in rain-fed and semi-arid regions. To address these challenges, the agricultural sector is adopting resilient, climate-smart practices that promote sustainability. Among them, the Broad Bed Furrow (BBF) system has emerged as a viable land management technique for mitigating climate risks. The BBF method characterized by alternating raised beds and furrows effectively addresses soil erosion, waterlogging, and inefficient water usage. Its implementation using specialized BBF planters enhances drainage, improves soil conservation, and increases crop yields. Field studies in Maharashtra and Madhya Pradesh, India, have shown that BBF technology significantly improves the performance of crops like soybean, chickpea, and pigeon pea. Yield increases of over 9% and improved economic returns have been documented in BBF plots compared to traditional systems. Given its success, BBF adoption expanded from 65 hectares in 2023 to 150 hectares in 2024. As climate variability continues to intensify, scaling up BBF technology offers a practical pathway toward sustainable, resilient agriculture.

Introduction

Climate change has become a critical factor affecting global agricultural productivity, especially in developing nations where farming systems are heavily reliant on monsoon patterns and consistent weather conditions. Temperature fluctuations, irregular precipitation, and the frequency of extreme weather events increasingly threaten soil health,

water availability, and crop reliability (FAO, 2021).

In response, climate-smart agriculture (CSA) is being embraced as a strategic approach to enhance resilience, reduce emissions, and promote productivity (World Bank, 2016). One practical intervention under CSA is the Broad Bed Furrow (BBF) system, a land configuration technique that involves creating a series of raised beds alternating

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with shallow furrows across a field. This layout helps manage water flow, reduce erosion, and conserve soil moisture. Broad Bed Furrow is particularly well-suited to semi-arid and rain-fed environments where rainfall is erratic and soil degradation is prevalent (Patil *et al.*, 2022). Using a Broad Bed Furrow planter, farmers can form uniform beds and furrows, ensuring precise seed placement, better soil aeration, and effective runoff management. This design allows for quick drainage during heavy rains and efficient water retention during dry spells. These advantages contribute to better root development, nutrient uptake, and ultimately higher yields.

Advantages of BBF Technology

The Broad Bed Furrow system offers several agronomic and economic benefits:

Enhanced Drainage: The furrows allow for rapid water evacuation, mitigating waterlogging during intense rainfall events.

Soil Conservation: Raised beds reduce topsoil erosion and help maintain soil fertility over time.

Water Efficiency: The system preserves moisture in the root zone while preventing surface runoff, making it suitable for both drought and flood conditions.

Yield Improvement: Improved soil structure and moisture regulation promote vigorous plant growth and higher productivity. In Indian states such as Maharashtra and Madhya Pradesh, Broad Bed Furrow technology has been particularly effective for crops like soybean, chickpea, and pigeon pea, contributing to higher yields and better climate

resilience.

Performance and Impact

BBF field performance metrics demonstrate its efficacy:

Machine Width: 2.1 meters

Operating Speed: 3 km hr⁻¹

Fuel Consumption: 3 liters acre⁻¹

Seed Rate: 20-22 kg acre⁻¹

Field Capacity: 0.63 ha hr⁻¹

Plant Population: >99% accuracy

Row Spacing: 18 inches

Field demonstrations showed a yield of 22.56 q ha⁻¹, a 9.62% increase over traditional systems (20.58 q ha⁻¹). Moreover, the Benefit-Cost ratio (B:C) improved to 2.1 for BBF plots compared to 1.9 in control plots, reflecting enhanced economic viability.

Conclusion and Outlook

The growing adoption of Broad Bed Furrow from 65 hectares in 2023 to 150 hectares by the end of 2024 highlights its practicality and effectiveness in real-world farming conditions. As climate extremes become more frequent, scaling up Broad Bed Furrow technology will be vital for sustaining agricultural productivity, enhancing farmer incomes, and securing food systems in vulnerable regions.

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Landscaping Practice and Sustainable Design: Concise Review

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Abstract

Landscaping, as a facet of environmental design and urban planning, plays a crucial role in harmonizing built environments with natural ecosystems. Over the centuries, landscaping styles have evolved under cultural, geographic, and technological influences from formal Mughal and Persian gardens to the relaxed elegance of English landscapes. In the face of rapid urbanization and ecological degradation, sustainable landscaping has emerged as a holistic approach to design that emphasizes resource efficiency, biodiversity, and ecological resilience. This paper explores the classification of landscaping styles, elements of hardscape and softscape, and recent advancements such as vertical gardening and xeriscaping. The integration of aesthetic, functional, and environmental design principles is discussed in detail, providing insights into how modern landscaping can address both human and ecological needs. By synthesizing traditional landscaping wisdom with contemporary innovations, this review underscores the vital role of sustainable practices in shaping livable and resilient urban futures.

Introduction

Landscaping transcends ornamental gardening to embody a multidisciplinary practice that fuses aesthetics, ecology and functionality. As a foundational aspect of landscape architecture, it involves deliberate planning and modification of outdoor environments to enhance ecological value, usability, and visual appeal. Traditionally shaped by regional climates, social customs, and architectural styles, landscaping has evolved into a dynamic field incorporating cutting-edge technologies and sustainable strategies. The impetus for sustainable landscaping has grown as urban environments grapple with climate change, loss of green cover, and increased pollution. By focusing on native species, resource conservation, and ecosystem integration,

sustainable landscape design offers a path forward for cities aiming to balance development with ecological integrity. This article systematically explores the different landscaping styles formal, informal, and mixed alongside the key features and materials that define contemporary landscapes. Additionally, it sheds light on advanced methodologies, including vertical gardening, xeriscaping, and bio-aesthetic planning, that are revolutionizing the way green spaces are conceived and maintained.

Styles of Landscaping: A Historic and Functional Classification

Formal Landscaping: Formal landscaping emphasizes symmetry, proportion, and axial geometry. Rooted in ancient Egyptian and Roman traditions and later refined in Mughal, French, and Italian

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garden styles, it uses structured layouts with clear focal points. Formal gardens, such as the Gardens of Versailles or Shalimar Bagh, showcase meticulously trimmed hedges, terraced levels, water channels, and ornamental sculptures, reflecting control over nature and spatial order.

Informal Landscaping: Informal landscaping, in contrast, mimics natural patterns. It gained prominence in Far Eastern traditions, particularly in Chinese and Japanese gardens, and spread to Europe during the 18th century. Characterized by asymmetry, free-flowing forms, and an abundance of perennials, informal gardens offer a sense of organic spontaneity. They evoke emotional resonance rather than architectural precision, using climbing plants, wildflowers, and natural terrain to create immersive environments.

Mixed Landscaping: Mixed landscaping integrates elements of both formal and informal styles, allowing designers to tailor landscapes to context and functionality. This approach is prevalent in modern urban parks, institutional campuses, and community gardens, where aesthetic order is blended with ecological diversity and practical use.

Global Garden Styles: Cultural Significance in Landscaping

Landscaping styles are often deeply embedded in cultural and historical narratives. The Mughal gardens, for instance, symbolize power and paradise, with symmetrical layouts, central water features, and fragrant plants. Persian gardens incorporate terraces and water canals to reflect spirit-

ual ideals of paradise, while English gardens emphasize naturalistic beauty, winding paths, and mixed flora.

Other regional styles include:

French Gardens: Structured grandeur with elaborate parterres, fountains, and axial paths.

Italian Gardens: Influenced by Roman architecture, featuring terraces, statues, and rose gardens.

Japanese Gardens: Minimalist, using rocks, moss, and water to evoke tranquility.

Each style reflects a unique interpretation of human interaction with the landscape and offers lessons in balance, aesthetics, and utility.

Elements of Landscaping: Hardscape and Softscape Integration

Landscaping comprises both hardscape (non-living elements) and softscape (living elements). Together, they create functional and visually cohesive outdoor spaces.

Hardscape Elements: Hardscape features such as pergolas, bridges, garden walls, paths, and trellises provide structural definition. They enhance usability by guiding movement, creating zones of activity, and supporting plant growth. Sustainable hardscape design emphasizes the use of local, permeable, and recycled materials to minimize environmental impact.

Softscape Elements: Softscape includes lawns, shrubs, flower beds, topiary, and hedges. The selection of native and drought-tolerant plants is crucial for low-maintenance, eco-friendly design. Additionally, components such as carpet beds, rock-

eries and topiary art contribute to visual interest and biodiversity.

Urban Landscaping and Gardening Practices

Urban green spaces are essential for mental well-being, pollution mitigation, and community interaction. Emerging urban landscaping practices include:

Home/Kitchen Gardening: Encourages local food production and recreational gardening.

Community Gardens: Foster collective cultivation and social bonding.

Vertical Gardening: Optimizes vertical space in dense urban areas; minimizes land use and irrigation demands.

Container Gardening: Offers flexibility in design, especially in balconies, patios, and rooftops.

Soilless Cultivation: Methods such as hydroponics and aquaponics allow efficient plant growth in limited space.

Principles of Sustainable Landscaping

Sustainable landscaping integrates long-term ecological stability with immediate visual and functional needs. Key principles include:

Design Simplicity and Balance

Simplicity avoids visual clutter, while balance symmetrical or asymmetrical ensures harmony. The focal point concept is used to direct attention, often through sculptures, water features, or striking plants.

Environmental and Functional Design

Designs are tailored to local microclimates, incorporating shading, drainage, and wind breaks.

Proportion ensures size compatibility among landscape elements. Functional considerations include accessible pathways, drainage systems, and utility zones.

Aesthetic Unity: Visual elements such as contrast, harmony, and repetition help achieve unified compositions. Sustainable landscapes may appear naturalistic but still adhere to aesthetic guidelines.

Core Components of Sustainable Landscapes

Water Efficiency: Efficient irrigation systems, such as drip irrigation and rainwater harvesting, reduce water waste. Sustainable designs aim to meet plant needs while minimizing evaporation and runoff.

Soil Health and Mulching: Healthy soil supports root systems, prevents erosion, and improves water retention. Organic mulches like leaf litter and paddy straw enhance fertility and control weeds.

Air Quality and Biodiversity: Trees and shrubs filter air pollutants and offer habitats for birds and insects. Native species, such as *Azadirachta indica* and *Ficus infectoria*, are especially effective in improving air quality and ecological health.

Energy and Waste Management: Landscapes can reduce energy use through natural shading and insulation. Waste is managed through composting, reducing landfill dependency and enriching soil with organic matter.

Innovations in Sustainable Landscaping

Xeriscaping: Xeriscaping is a drought-resistant landscaping technique that minimizes irrigation through the use of native, slow-growing plants. It is especially useful in arid regions but is adaptable to

most climates through soil moisture zoning and smart irrigation systems.

Bio-Aesthetic Planning: This approach integrates native flora with aesthetic design, especially in rural and semi-urban areas. It promotes environmental education, biodiversity, and ecosystem resilience through carefully curated green spaces.

Conclusion

Landscaping is no longer a luxury it is a necessity for sustainable living in an urbanized world. This review of diverse landscaping styles and sustainable design practices reveals how outdoor spaces can be transformed into ecologically functional, culturally rich, and visually captivating environments. By embracing traditional garden styles and contemporary ecological innovations, landscape architects, urban planners, and individuals can foster green spaces that benefit both people and the planet. The future of landscaping lies in its adaptability, inclusivity, and commitment to sustainability ensuring that every green space contributes meaningfully to the health of our cities and ecosystems.

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Beyond GMOs: Gene Editing from Crops to Cures

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Abstract

From selectively bred cornfields to gene-edited rice and life-saving therapies, humanity's journey in shaping life has entered a revolutionary new chapter. This article explores how CRISPR-Cas9, a precise and powerful gene-editing tool, is transforming the way we approach agriculture, medicine, and biotechnology. Unlike traditional GMOs, CRISPR edits DNA without introducing foreign genes sidestepping many of the controversies that have long surrounded genetic modification. Highlighting India's pioneering genome-edited rice and the world's first personalized CRISPR therapy for a rare genetic disorder, this piece examines how gene editing is making science faster.

Introduction from Beginning of the Civilization to Genetic Frontiers

What if we could grow rice that not only feeds more people but also helps fight climate change? Or cure a life-threatening genetic disorder in a baby using a microscopic tool?

For thousands of years, humans have tried to shape nature to better serve our needs domesticating wild species, selecting the best traits, and crossbreeding plants and animals to improve size, flavor, strength or productivity. Modern strawberries are the result of crossing a North American strawberry species with one from South America. In fact, much of the food we consume today has been developed through traditional breeding. However, this process of modifying plants and animals through conventional methods is often very time-consuming. To develop any variety it will take a breeder around 15-17 years, some methods like bulk breeding method may take even longer upto 20-30 years

depending upon the objective. Sometimes, when farmers try to improve one trait in a plant, they unintentionally introduce unwanted ones too. With the advent of gene-editing technologies like CRISPR-Cas9, scientists can make precise, targeted changes to an organism's DNA faster, safer, and without introducing foreign genes. From fields to hospitals, CRISPR is quietly launching a revolution that could reshape how we feed, heal, and protect the world

The GMO Era: a Biotech Revolution

The time and effort intensive conventional breeding has been reduced drastically with the advances in molecular biology and biotechnology. In 1973, biochemists Herbert Boyer and Stanley Cohen pioneered genetic engineering by transferring DNA from one bacterium into another. This has led to the first Genetically Modified Organism (GMO) reported in 1974 by the virologist Rudolph Jaenisch, then at the Salk Institute and the mouse embryologist

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Beatrice Mintz at Fox Chase Cancer Center. They demonstrated the feasibility of modifying genes in mice by injecting the SV40 virus into early-stage mouse embryos. In plants first GMO was a transgenic tomato which became available for sale after studies evaluated by federal agencies proved it to be as safe as traditionally bred tomatoes. From these pioneering milestones many new breakthroughs brought many GMOs like GM Maize, GM rapeseed and mustard (also known as Canola), GM Soybean, GM papaya, GM apple etc in the developed countries of the world.

India's GMO landscape: Progress and Pause

In this GMO race, India is lagging a little behind. To date, India's GMO regulatory authority, the Genetic Engineering Appraisal Committee (GEAC), has approved only one genetically modified crop for commercial cultivation *Bt* Cotton. This crop has significantly transformed the textile industry. *Bt* Cotton now accounts for about 95% of cultivated cotton in India, significantly reducing the use of traditional varieties. Our country also has developed many transgenic varieties of crop but due to its hard and fast scrutiny system, none of them except cotton has got commercial approval.

Concerns related with GMO

The main reasons behind it are health concerns, environmental concerns and ethical issues. In any GMO product, genes from another organism (transgene) has been incorporated so there's always a health concern that it might be the reason of allergies to some people or the unforeseen risk to our

health in long run, also since it solves a major flaw of conventional varieties so its popularity may become risk to the present biodiversity, the ethical concern addresses the unpredictable consequences of introducing these organisms in the natural ecosystem, IPR related issues like biopiracy etc.

CRISPR: Discovery of the Decade

But things have now changed with the major breakthrough in molecular biology and biotechnology with the discovery of the CRISPR-Cas 9 system. CRISPR (Clustered Regularly Interspaced Palindromic Repeats) is a segment of DNA containing short repetitive base sequences, natural defence mechanism in bacteria. Cas-9 is nothing but a CRISPR associated protein, an enzyme which acts as molecular scissors. Because it cuts the genomic DNA at specific sequences guided by a piece of RNA called gRNA. Emmanuelle Charpentier and Jennifer Doudna discovered how CRISPR can be used to edit DNA by programming to cut DNA at specific locations, creating a powerful new tool for gene editing. For this novel discovery they both were awarded the Nobel Prize in chemistry the year 2020.

How is this gene editing different from the traditional GMO?

In a GMO, a transgene is incorporated into the host genome by various means whose expression creates new traits which are not naturally present. That is why it is called transgenic but on the other hand gene editing through CRISPR no foreign genes from other species are added, changes are made within the organism's own DNA. It's like using a

“find and fix” tool to correct or delete a gene.

CRISPR in Action: Climate Resilient Rice Variety and Life Saving Therapy

Recently, it is in the news as the world's first genetically edited rice has been developed in India - DRR Dhan 100 (Kamala) and Pusa DST Rice 1 by Indian Institute of Rice Research, Hyderabad of ICAR (Indian Council of Agricultural Research). Apart from its yield advantage upto 20-30%, it can reduce the methane emission by 20% and is more stress tolerant with better nitrogen use efficiency than its parent variety, Samba Mahsuri (BPT 5204) making it suitable for climate resilient agriculture. Since the genome-edited line contains no foreign DNA, it is exempted from the strict biosafety regulations of Environment Protection Act, 1986. These regulations govern both field trials and release for commercial cultivation in the case of GM crops. Though a network of organisations and individuals advocating for a GM-free India has demanded that govt immediately withdraw the two genome-edited rice varieties and bring them under the purview of rigorous regulation. Institutional Biosafety Committees (IBC) of ICAR approved the lines while the Review Committee on Genetic Manipulation (RCGM) cleared them in May 2023 and declared them safe under India's simplified regulatory framework. Another recent breakthrough in medical science is the first ever personalized CRISPR treatment used to treat a nine and half month-old baby with a rare genetic mutation. This baby boy, KJ Muldoon was diagnosed shortly after birth with

Carbamoyl Phosphate Synthetase 1 (CPS1) deficiency, a rare and severe metabolic disorder. This condition prevents the liver from properly breaking down nitrogen, leading to the dangerous buildup of ammonia in the blood, which can cause brain damage or even death if untreated. A team at the Children's Hospital of Philadelphia developed a custom CRISPR-Cas9 therapy tailored to correct the exact mutation in this infant's CPS1 gene. CRISPR-Cas9 is a groundbreaking technology that functions like molecular scissors, enabling scientists to precisely cut and repair defective sections of DNA. The treatment was delivered directly to the infant's liver cells using a specially engineered virus. This approach is notable for being both personalized and somatic meaning it was designed for his unique DNA and only affects body cells (not inherited by future generations). After the treatment, the baby has shown significant clinical improvement. He is now able to tolerate higher levels of dietary protein and requires less medication to control ammonia levels which clearly indicates the success of the therapy. However, the doctors will continue to monitor the baby over time to assess the long-term effectiveness and safety of the therapy. If successful, this personalized approach could open the door to treating other rare and previously untreatable genetic conditions.

Conclusion: a future rewritten by CRISPR

In a world grappling with climate change, food insecurity, and rising health challenges, modern technologies of molecular biology and biotechnolo-

gy have emerged as the need of the hour. Whether it's developing climate-resilient crops like DRR Dhan 100 that reduce methane emissions or pioneering personalized medical therapies for rare genetic disorders, the technology offers solutions that are both sustainable and scalable. Scientists have been facing many ethical setbacks to achieve such a feat by transgenics which can be overcome now with the help of gene-editing technology. Gene editing, especially through tools like CRISPR-Cas9, represents a transformative leap beyond traditional GMOs. Unlike GMOs, which involve inserting foreign genes into an organism often raising concerns about health, biodiversity, and ethics gene editing makes precise, targeted changes within an organism's own DNA without introducing foreign genetic material. This subtle yet powerful distinction not only addresses many of the regulatory and public apprehensions but also opens doors for faster, safer, and more acceptable innovations. As we face growing global challenges, CRISPR may be one of the smartest tools in humanity's toolbox-if used wisely.

Phytochemical Richness of Beetroot: A Focus on Bioactive Compounds

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Introduction

Beetroot (*Beta vulgaris* L.) is classified within the family Chenopodiaceae and is believed to have originated in the regions of Asia and Europe. The Chenopodiaceae family encompasses approximately 1,400 species which are further categorized into 105 distinct genera, with all members belonging to the dicotyledonous classification. Beetroot is characterized as a flowering, true biennial or a perennial plant, exhibiting numerous varieties that display a spectrum of colors from yellow to red. The commercially available subspecies of *Beta vulgaris* consist of *B. vulgaris*, *B. maritima* and *B. adanensis*. Among these, *B. vulgaris* spp. *vulgaris* holds significant importance and is commonly referred to in commercial contexts as the common beet, sugar beet, or garden beet. The edible component of beetroot (*B. vulgaris* L.) is the root, which is elongated, tapered, and robust in structure. The morphology of the roots typically presents as globe or cylindrical in shape, displaying coloration that varies among red-purple, golden yellow, and red-white, contingent upon the specific variety of beets. As a cool-season vegetable, beetroot demonstrates a considerable tolerance to elevated temperatures, with an optimal growth temperature range between 15 to

19 °C. Lower temperatures are conducive to the enhancement of deep red pigmentation within the beetroot. Beetroot serves as a root vegetable rich in carotenoids, nitrates, flavonoids, vitamins, and minerals such as potassium, sodium, phosphorus, calcium, magnesium, copper, iron, zinc, and manganese, in addition to water-soluble pigments known as betalains, which include betacyanins (red-violet color) and betaxanthins (yellow-orange color), all of which confer various nutritional and health benefits. The polyphenols, carotenoids and vitamins of beetroot have antioxidant, anti-inflammatory, anticarcinogenic and hepato-protective activities and also have anti-diabetic, cardiovascular disease lowering, hypertensive and wound healing benefits. Therefore, utilization of beetroot as an ingredient in different food products imparts beneficial effects on human health and provides opportunity for development of different functional foods.

Bioactive compounds in beetroot

Phenols: Beetroot contains large levels of phenolic chemicals and flavonoids. Beetroot contains 50-60 µmol of phenolic acids per gram dried weight. Beetroot peel contains the second highest dry weight content of total phenols. The peel of beetroot contains betalains such as vulgaxanthin I, vulgaxa-

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anthin II, indicaxanthin, prebetanin, isobetanin, betanin, and neobetanin. Additionally, two phenolic amides, N-trans-feruloyltyramine and N-trans-feruloylhomovanillylamine, were found in beetroot seed walls.

Betalains: Betalains are water-soluble nitrogen-containing plant pigments. Betacyanin (red pigment) and betaxanthin (yellow pigment) were compared based on their chemical structures and compositions. Beetroot is one of the richest sources of betanin pigment, which is utilized to create a desirable red or yellow color. Beetroot varieties redness are determined by the ratio of betacyanin and betaxanthin. Betaxanthin is divided into two types: vulgaxanthin-I and vulgaxanthin-II. Beetroot peel contains many betacyanins, including betanin, prebetanin, isobetanin and neobetanin. About 75-95% betanin of the total betacyanin are classified as active components of beetroot.

Flavonoids: Flavonoids are physiologically active chemicals with a high antioxidant capacity and several health advantages. According to reports, the primary flavonoids found in beetroot were betagarin, betavulgarin, cochliophilin A, and dihydroisorhamnetin. Beetroot leaves yields two flavanones: betagarin (5,2-dimethoxy-6,7-methylenedioxyflavanone) and betavulgarin (2'-hydroxy-5-methoxy-6,7-methylenedioxyisoflavone). The ethyl acetate fraction of *B. vulgaris* ssp. *perennis* included quercetin, rutin, and 4'-hydroxy-5-methoxy-6,7-methylenedioxy flavanone.

Carotenoids: Carotenoids are phytochemicals that

contribute to the colour of fruits and vegetables and play an important role in disease prevention. Carotenoids found in beetroot function as antioxidants, anticarcinogens and immunostimulants. Beetroot has many carotenoids, which are powerful antioxidants. They have been shown to suppress mutagenesis, reducing cancer risk. Beetroot leaves contain β -carotene and oxygenated derivatives called xanthophyll, including lutein.

Applications of bioactive compounds of beetroot

Role of beetroot bioactive compounds in human health:

These chemicals have strong antioxidant properties, which assist to neutralize damaging free radicals in the body, reducing oxidative stress and protecting cells from damage. Betalains are also well-known for their anti-inflammatory qualities, which may help reduce the risk of chronic diseases like heart disease, arthritis, and certain malignancies. They have been proven to decrease the activity of pro-inflammatory enzymes and pathways, which promotes overall immunological health. Furthermore, betalains help in liver detoxification by breaking down and eliminating toxins via the body's natural phase II detoxification system. They may also help with cardiovascular health by decreasing blood pressure and enhancing blood vessel function due to their nitric oxide-boosting properties. Beetroot contains nitrates that can reduce blood pressure, protect against ischemia-reperfusion damage, and modulate mitochondrial function. It lowers bad cholesterol, oxidized LDL cholesterol, and normalises the blood pressure.

Beetroot extracts contain antihypertensive and hypoglycaemic properties. Betalains affect vascular homeostasis, platelet function, thrombotic activity, vascular tone, and the release of vasodilating and vasoconstricting agents by reducing homocysteine levels. Cardiovascular illnesses, including hypertension and atherosclerosis are known risk factors for endothelial dysfunction.

Role of beetroot bioactive compounds in food industry: Polyphenols and flavonoids in beetroot contribute to its antioxidant profile, helping in the preservation of food by delaying oxidation processes in fats and oils, thus extending shelf life. Their presence also aids in enhancing the functional appeal of foods aimed at preventing oxidative stress-related diseases. Dietary fibers from beetroot, such as pectin, are utilized in the development of functional foods and dietary supplements that promote digestive health and help in cholesterol regulation. These fibers can also serve as natural texturizers or gelling agents in bakery and processed food products. Moreover, beetroot bioactives show antimicrobial properties, which can inhibit the growth of certain foodborne pathogens, contributing to food safety and stability. The health halo around beetroot bioactives also boosts consumer acceptance and marketability of plant-based, organic, or health-conscious food items.

Conclusion

Beetroot is a remarkable functional food with a wide range of bioactive substances, including betalains, nitrates, polyphenols, flavonoids, and

dietary fibers. These compounds have significant health-promoting properties, including antioxidant, anti-inflammatory, cardioprotective and antimicrobial activity. Their inclusion into many food products boosts not only nutritional quality but also functional aspects such as color, texture, preservation, and overall consumer appeal. The use of beetroot bioactives in the food industry is a viable way to address the growing demand for natural, health-enhancing ingredients while simultaneously promoting the development of innovative and environmentally friendly food systems. Continued research and technology improvements will enhance their applicability, ensuring stability, efficacy, and broad industrial significance.

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Rambutan Cultivation: A Scientific Perspectives

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Rambutan (*Nephelium lappaceum* var. *lappaceum*) belongs to the Sapindaceae family and is indigenous to the Malay Archipelago. It is grown extensively throughout Southeast Asia. Sri Lanka and India also cultivate it. This evergreen tree can reach a height of 12 to 20 meters. The flowers of rambutan trees can be hermaphroditic, male, or female. The fruit resembles litchi in appearance and texture, but its skin features numerous long, thick, hairy projections that are yellow, pink, or red in color. Rambutan fruits grow in loose, pendant clusters of 10-20 drupes, which are round to oval in shape. The flesh (aril), which adheres to the seed, is 0.4-0.8 cm thick, translucent, juicy, acidic, sub-acidic, or sweet, and white or rose-tinted. The seed is 2-3 cm long, oblong, flattened, and glossy brown.

Rambutan fruits have a pleasant flavor and aroma and are juicy, sweet, and enjoyable. They contain sugars, vitamin C, and other essential vitamins and minerals. The fruit can be consumed fresh or processed into a variety of products. In India, rambutan is commercially grown in home gardens in the districts of Thrissur, Pathanamthitta, Kottayam, and Ernakulam in Kerala; Nagercoil, Courtallam, and the Nilgiris in Tamil Nadu; and Dakshina Kannada and Kodagu in Karnataka. It is estimated

that less than 1,000 acres are currently under rambutan cultivation in India, with most farms having fewer than 20 plants. There is significant potential for expansion of this crop in the country.

Climate and soil: Warm tropical climates are ideal for rambutan cultivation. Commercial production typically occurs within 12 to 15 degrees of the equator. The tree thrives at elevations of up to 700 meters above mean sea level. For optimal growth, it requires temperatures between 22°C and 30°C. Rambutan is extremely sensitive to cold; growth is significantly hampered at temperatures below 10°C. Low temperatures affect defoliation, panicle emergence and fruiting. Similarly, high temperatures (above 40°C) can negatively impact plant growth and development. Rambutan requires 200 to 500 cm of rainfall annually, distributed evenly throughout the year. However, a brief dry period is essential to initiate flower bud formation. Excessive rainfall during the fruit maturation stage can lead to fruit cracking. Rambutan can be successfully cultivated in a variety of soil types. However, well-drained sandy loam to clay loam soils rich in organic matter are ideal for optimal growth and yield. With adequate application of organic and inorganic fertilizers, cultivation is also possible in red laterite soils.

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The ideal soil pH range is 4.5 to 6.5. Rambutan is sensitive to water-logging, which can adversely affect its growth.

Varieties: There are over 200 cultivars developed from selected clones available throughout tropical Asia. Most commercial cultivars are hermaphroditic. Some of the promising varieties are Arka Coorg Arun, Arka Coorg Peetabh, E-35, N-18.

Propagation: Rambutan is propagated by seed, budding, grafting and layering. The seedlings are used for rootstock purpose. Seeds were sown in the nursery bags and it took around 25-28 days for germination. The seeds lose their viability very soon. Thus, they should be sown immediately after removing the aril. The storage of fresh seeds can be done in moist sawdust, sphagnum moss or charcoal for 3-4 weeks. The seedlings become ready for grafting in 9-10 months. Vegetative propagation is essential as rambutan seedlings take long time for fruiting and female to male trees ratio is 4/57. Among various budding methods, patch-budding and T budding have been found successful. The budding is done in the well-grown 8 to 12 months old rootstocks in May or July. The budwood selection is important for the success of the budding. A one-year-old budwood of 1.5 to 2 cm diameter is found more suitable. The removal of leaves 1 week prior to budding provides better success.

Planting: Due to their vigorous and spreading growth habit, rambutan seedling trees require ample space to canopy development. To avoid canopy overlap after 10 to 15 years, they should be planted

at a spacing of 10 m × 10 m to 12 m × 12 m. Vegetatively propagated trees are more compact and can be spaced more closely typically 8 m × 8 m or 8 m × 6 m. Planting is carried out in pits measuring 1 m × 1 m × 1 m, which should be dug 2 to 3 weeks prior to planting. These pits are filled with a mixture of one part compost and three parts topsoil. For optimal establishment, planting is best done in June or July, shortly after the onset of the monsoon, to take advantage of the seasonal rainfall and ensure strong root development by the end of the rainy season.

Training and pruning: Rambutan trees exhibit strong apical dominance and a tendency for long, upright growth. Early training and pruning are recommended to develop an open-center canopy structure. After harvesting, fruiting twigs should be pruned back to encourage the growth of up to four new lateral shoots, approximately 22% of which are expected to bear fruit in the following season. Regular removal of water sprouts (suckers) and dead or diseased branches is also advised to maintain tree health and productivity.

Nutrition: A fertilizer dose of 200 g N, 25 g P and 100 g K tree⁻¹ year⁻¹ of age is recommended for rambutan. For the first four years, the fertilizers should be applied in four equal dressings, every three months. After four years 200 g N, 25 g P and 130 g K tree⁻¹ year⁻¹ of age is recommended. The dose should be increased up to twelve years and 2,400 g N, 300 g P and 1,560 g K should be given to 12-year-old trees and should remain constant thereafter. For fruiting trees, one-fourth of the yearly fertilizer

should be applied four weeks after fruits set, half the amount should be applied immediately after harvest and the remaining one-fourth at nine weeks after harvest.

Irrigation: Irrigation should be provided as needed during dry seasons. Strong winds must be avoided, as they can damage rambutan trees, especially during the flowering and fruiting stages. To induce flowering in fully mature rambutan plants, a dry period of approximately 21-30 days is required. The primary purpose of irrigation following this dry spell is to initiate floral bud development. Flowering typically begins 10 to 15 days after re-watering.

Interculture: Mulching is essential during dry periods and the plant establishment phase. However, mulching should be avoided before flowering. Glyphosate should never be applied near irrigation lines or around the tree basin, as it can cause severe yellowing and abscission of the lower leaves.

Pollination and fruit set: Three types of flowers are observed in rambutan-staminate (m), hermaphrodite functional female, and hermaphrodite functional male. The hermaphrodite cultivars that produce only functionally female flowers require the presence of male trees. Male trees are seldom found because vegetative selection has favoured hermaphroditic clones that produce a high proportion of functionally female flowers and a much lower number of male flowers that produce pollen. Peak flowering season in Coorg was noticed in March. In the hermaphrodite functional male type, cross pollination is essential for fruit set.

Diseases and pests: Rambutan is affected by various insect pests across different growing regions, but only a few have the potential to cause significant outbreaks. As rambutan is a relatively new crop in our country, limited research has been conducted on its diseases and insect pests. So far, only minimal damage from insect pests has been observed. Notable diseases include twig blight, stem cankers, and powdery mildew, while mealy bugs, beetles, and other bugs are considered important pests. However, both disease incidence and pest infestations have remained relatively low to date.

Harvesting and post-harvest management

Grafted rambutan trees typically begin to bear fruit in the fourth year. After fruit set, it may take up to five months for the fruits to fully mature. In India, rambutan produces only one crop per year, with fruit ripening generally occurring between July and October. Harvesting is done by cutting the flower stalk using shears or sharp knives. Each fruit is then separated and packaged individually. As rambutan fruits are delicate, have a short shelf life, and bruise easily, they should not be dropped or left on the ground. An average tree can yield between 5,000 and 6,000 fruits (approximately 60 to 70 kg). However, due to the rambutan's tendency for alternate bearing, yields can vary from year to year. To extend shelf life, harvested fruits should be stored at temperatures between 13°C and 15°C and wrapped in plastic thick enough to prevent moisture loss. Cold storage at this range helps maintain firmness and gives the fruit a more transparent appearance.

Additionally, sucrose content tends to increase during storage. However, temperatures below 7°C can cause chilling injury, leading to damage of the peel and the fruit's characteristic hairy projections.

The Future of Food: How Genetic Engineering is Revolutionizing Food

Ayush Raj

Abstract

The future of food is being transformed by genetic engineering, a groundbreaking technology in plant breeding. With increasing global challenges such as climate change, population growth, and food malnutrition, genetic engineering provides innovative solutions to enhance crop resilience, nutritional value, and sustainability. By directly altering the genetic structure of plants, scientists can develop crops that resist drought and pests and have higher nutritional value, tackling critical issues like malnutrition and environmental degradation. This article examines how genetic engineering is accelerating the creation of climate-adaptive crops, improving food security, and minimizing the ecological footprint of conventional agriculture. It also highlights the potential of gene editing tools like CRISPR, which facilitate more precise and faster breeding methods. Although ethical concerns and public perception persist, the potential of genetically engineered crops to nourish a growing global population is indisputable. As technology advances, genetic engineering is helping to play a crucial role in ensuring a sustainable and plentiful food supply for future generations.

Introduction

Understanding Genetic Engineering in Plant

Breeding: Plant breeding is the science of improving crops to meet human needs. Traditionally, this was done through selective breeding, where the best plants were crossbred to produce offspring with desirable traits. While effective, this method can be slow, taking many years or even decades to develop new varieties. Genetic engineering changes this by allowing scientists to modify a plant's DNA directly to introduce specific traits, such as disease resistance or improved yields. This approach is faster and more precise and can introduce characteristics that may not be achievable with traditional breeding.

Revolutionizing Crop Resilience: One of the major benefits of genetic engineering is its ability to create

crops that can endure harsh environments. As climate change intensifies, many crops face new challenges like droughts, extreme heat, and soil degradation. Genetic modification enables crops to become more resilient to these stresses. For example, drought-resistant corn is already in use, helping farmers in water-scarce areas maintain high-quality yields. Similarly, salt-tolerant rice is being developed for regions suffering from soil salinization, making it a viable crop in places where traditional varieties fail. In areas severely impacted by climate change, these modified crops offer a critical solution for ensuring stable food production despite difficult conditions.

Enhancing Nutritional Value: Crops for Better

Health: Genetic engineering is also improving the nutritional content of crops. One notable example is

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Golden Rice, engineered to produce higher levels of Vitamin A, which can help combat Vitamin A deficiency, a leading cause of blindness and immune problems in children in developing nations.

Beyond Golden Rice, scientists are working on a range of crops with improved nutritional profiles, including:

- ✓ Iron-fortified beans to fight iron-deficiency anaemia.
- ✓ Vitamin-enriched maize for areas with limited dietary variety.
- ✓ Omega-3 enriched soybeans to promote better heart health.

These biofortified crops have the potential to significantly reduce malnutrition in low-income regions where access to diverse, nutrient-rich foods is limited.

Reducing Pesticide Use: Genetic engineering can also help reduce the need for chemical pesticides, which have harmful environmental effects. Pests and diseases threaten crops globally, and insecticides and herbicides contribute to pollution, harm beneficial species, and create pesticide-resistant pests. Genetically modified crops, such as *Bt* cotton, which produces its insecticidal protein, have greatly reduced the need for chemical insecticides, benefiting both farmers and the environment. Similarly, genetically modified papaya, resistant to the papaya ringspot virus, saved the Hawaiian papaya industry from collapse. By minimizing the use of chemical treatments, these crops lower farming costs and reduce agriculture's environmental footprint.

The Future of Genetic Engineering in Plant

Breeding: The future of genetic engineering in plant breeding is increasingly promising. Tools like CRISPR-Cas9 are revolutionizing the field, allowing for precise genetic modifications without introducing foreign genes, making the process more natural and widely accepted.

Conclusion

Genetic engineering has great potential to change plant breeding, offering solutions to major problems in agriculture today. By creating crops that can better withstand climate change, provide more nutrients, and need fewer pesticides, this technology could help improve food security and protect the environment. Although there are still concerns about the ethics and safety of genetically modified crops, continued research, regulation, and education can address these worries. As genetic engineering advances, it promises a more efficient, sustainable, and healthier food system. By working together globally, this innovation could play a key role in feeding the growing world population while addressing environmental and nutrition challenges.

Medicinal Plants: Awareness and Cultivation Need to be Promoted

Deepanjali Maurya, Hari Baksh and Aman Srivastav

Medicinal plants occupy an important position in human healthcare to cure the different ailments in traditional and recognized wellness system. These plants have great value in therapeutics, fragrance and flavouring, pharmaceutical and cosmetic industries. Medicinal plants are rich in secondary metabolites viz. Alkaloids, glycosides, coumarins, flavonoids and steroids.

Medicinal plants have natural power to cure us and keep healthy without any side effects. Ayurvedic Medicines and their products today have become a symbol of safety in contrast to allopathic drugs that are considered unsafe and hazardous in long term. Many plants species are used for the purpose of medicines since ancient times to heal wound and cure diseases to improve the health of human beings. In this planet thousands of medicinal plants are found but only few are known and used by humans. India is blessed with the varied agroclimatic conditions harboring wide variety of medicinal plants. India has maximum medicinal plants and ranks 1st in the world as a leader in Cultivation, Utilisation & Production of medicinal and aromatic plants. These plants are mostly used as home remedies for treating seasonal flue, viral infections, cough, cold, stomachache, sore throat & headaches.

More than 60% of medicines are plant based and different parts of a plant like -leaves, stems, roots, seeds, flowers and fruits have different medicinal properties containing compounds. Medicinal plants are also valuable for food and cosmetic industries as additives due to their preservative effects because of having antioxidants and antimicrobial properties. Now a days Medicinal, Aromatics, Plantations and Spices (MAPs) has been recognized a separate discipline in Horticulture. Some well-known medicinal plants and their properties are discussed in this article.

Ashwagandha (*Withania somnifera*): It is a



perennial herb but grown as annual. The major chemical constituents are withanine and somniferine. It has

aphrodisiac, febrifuge, demulcent, diuretic, sedative and adaptogenic properties. It is also used against stress, fatigue, joint pain and improve improper digestion. It is native to India & belongs to the Solanaceae family. Jawahar Asgandh-20, Jawahar Asgandh-134, Rakshita, Poshita, MWS-216, MWS-226, RAS-10, WS-119 are its high yielding varieties.

Sarpagandha (*Rauvolfia serpentina*): It belongs to family Apocynaceae. The major chemical constitu-

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ents are serpentine, reserpine, ajmaline, ravolfinine are mostly found in its root part. It is used for the control of hypertension, fever, insomnia, epilepsy and dyspepsia.



The roots have laxative, anthelmintic, diuretic and sedative properties. It is also useful in snakebites, insect stings, nervous disorders, menopauses, menstrual disorder, diarrhoea and dysentery. CIM-SHEEL, RS-1 are high yielding varieties of Sarpagandha.

Safed musli (*Chlorophytum boribilianum*): It



belongs to the family Asparagaceae. The major chemical constituent is saponins mostly found in its root. It is used to cure impotency, rheumatism, diabetes, asthma, diarrhoea and dysentery. Jawahar Safed Musli, RC-2, RC-16, RC-23, RC-36 are important varieties.

Psyllium/Isabgol (*Plantago ovata*): The major chemical constituents are xylose, arabinose, galacturonic acid, rhamnose, and galactose. It is used for the treatment of constipation, chronic amoebic or bacillary dysentery, inflammation and intestinal disorders.

Giloy (*Tinospora cordifolia*): It belongs to family



Menispermaceae and native of India. The major chemical constituents are Berberine and Palmatine. It has antioxidant, anti-inflammatory and immune

modulating properties. It is also known as Heart leaved moonseed plant, Guduchi, Amrita and Giloya.

Glory lily (*Gloriosa superba*): It is also known as Flame lily and Malabar glory. Rich source of two major alkaloids- Colchicine and Gloriosine which is present in tuber and seeds. It is used in the treatment of joint pains and rheumatism. It is a perennial tuberous climbing herb, extensively found in the Tropical and Subtropical countries of the world.

Bobchi (*Psoralea corylifolia*): The major chemical constituent is Coumarins. It is use in leucoderma, leprosy, psoriasis, kidney yang deficiency enuresis and urinary frequency. It belongs to the Fabaceae family.

Foxglove (*Digitalis lanata*): Its family is Plantaginaceae and economic part is leaves. The major chemical constituents is Digoxin. It is used to cure heart diseases.

Guggal (*Commiphora wightii*): The major chemical constituents are Z and E gugglusterone. It is used in treatment of arthritis and obesity. It has anti-inflammatory, hypoglycemic properties. GAU-Marusudha is an improved variety and Economic product is Gum resin.

Belladonna (*Atropa belladona*): Its major chemical



constituents are Atropine and Hyoscyamine. It is used in neurologic pain. It is also used as truth confessor in criminological investigation.

Henbane (*Hyoscyamus niger*): It belongs to the family Solanaceae & major chemical constituents are

hyoscyamine, atropine, tropane and scopolamine. It is used in treatment of asthma, whooping cough and intestinal disorder. Jawahar Henbane-1, HMI-80-1 are important varieties.

Senna (*Cassia angustifolia*): The major chemical



constituents- sennosides A, B, C, D. It cures skin diseases and has laxative and anthelmintic properties. It stimulates liver and is also

used to treat jaundice, cough, bronchitis and anemia. Sona, ALFT-2, Linnevali, KKM-1 are some important varieties.

Long pepper (*Piper longum*): It belongs to the family Piperaceae. The major chemical constituent is Piperine. It is used in treatment of chronic bronchitis, asthma, constipation and gonorrhea.

Periwinkle/Vinca (*Catharanthus roseus*): It belongs to family Apocynaceae. Major chemical



constituents present in roots- Raubasine, and in leaves - Vincristine & Vinblastine. It is used in cancer therapy. CIMAP-Nirmal, CIMAP-Dhawal are important varieties

of periwinkle.

Besides these, many more medicinal plants like- Neem, Tulsi, Aloe, Mint, Turmeric, Ginger, Mulathi, Dill, Opium, Cinchona, Dhatura, Ipecac, Gale of the wind, Vallari, Adhatoda etc. also have many health benefits for living beings. Treatment with herbal medicinal plants also hold a strong

ground because these plants are considered to be safe and have no side effects. The main Goal of World Health Organization (WHO) “Health for all” can’t achieved without herbs. In India many organizations engaged in promotion, cultivation, utilization, management, research and processing of MAPs are ICAR-DMAPR, CSIR-CIMAP, NMPB etc. DMA PR- Directorate of Medicinal Aromatic Plantation Research, Anand, Gujarat is an important organization which gives information about how the medicinal and aromatic plants cultivation is becoming a popular field in the Agro-industry which is changing the lifestyle of numerous growers and entrepreneurs.

CIMAP- Central Institute of Medicinal & Aromatic Plants, Lucknow, Uttar Pradesh is a frontier plant research laboratory of Council of Scientific and Industrial Research. CIMAP is a unique lab of its kind in the entire globe. It is conserving the plant genetic resources systematically and undertaking world class research work in plant science. CIMAP is equipping the nation with high-tech agriculture linked to industrial processing of MAPs.

NMPB- National Medicinal Plants Board, New Delhi, provides a range of facilities and support to farmers involves in the cultivation & collection of medicinal plants. These include- Training and Capacity Building, financial Assistance for Nursery Maintenance, Information, Education and Communication (IEC) Activities, Marketing support, Minimum Support Price (MSP), Species-Specific

Campaigns, Institutional strengthening (SMPBs), Infrastructure support and Market Information Services. The NMPB's approach to support farmers success, contributing to the conservation of India's rich Bio-diversity of MAP's while promoting economic growth and jobs in Rural areas. The Indian Government and National Bank for Agriculture and Rural Development are offering many policies and financial supports to Encourage scope of MAPs cultivation and overall production. Ayurvedic medicines are known to treat the diseases from the root and thus aid in keeping us healthy and fit in the long run.



Urban Rooftop Revolution: Growing Greens and Fish in City Spaces

Bharath G. and Murtaza Hasan

Abstract

With rising issues related to food accessibility in urban areas, diminishing farmland, and the need for more sustainable practices, a new type of farming method called urban rooftop aquaponics is being developed on the rooftops of structures. This method creatively utilizes the concern of vacant city spaces, turning future food systems and eco-consciousness into reality, thereby tackling many metropolitan problems. This technique not only uses untapped city resources, but also aims to solution the issues of farmland loss and resource depletion.

The Urban Food Crisis

Approximately 70% of the global population is estimated to live in cities by 2050. Currently, cities grow less than 10% of the food they require. From climate change, soil erosion, and water scarcity, traditional farming struggles to keep up with the increasing demand, and people living in cities face the issue of food deserts that further limit their access to wholesome fresh food. The average food item travels over 1,500 miles before reaching urban consumers, their storage in refrigerated conditions or transportation takes a toll on their nutritional value while adding to greenhouse gasses. The urban rooftop aquaponics system, a new-age solution toward modern farming, combines aquaculture with hydroponics, growing plants and fish in a mutually beneficial closed environment where fish waste offers nourishment to plants. In turn, the plants filter and cleanse the water for the fish, creating a symbio-

tic relationship. This system propels food production in urban areas with low space and resources, enabling roofs to be transformed into productive areas for locally grown protein and vegetables.

Technical Innovation and System Design: Modern rooftop aquaponics systems have evolved from simple backyard experiments to sophisticated urban farming operations. These systems typically consist of fish tanks, biofilters, and hydroponic growing beds connected through recirculating water systems. The key innovation lies in optimizing these components for rooftop conditions, including wind exposure, temperature fluctuations, and structural load limitations. Recent advance technologies in system design have made rooftop installations more easy and productive. Lightweight growing media, efficient water circulation systems, and climate-controlled environments made year-round production even in challenging urban microclimates.

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Table 1: Comparison of Urban Food Production Systems

Production System	Space Efficiency (kg m ⁻² year ⁻¹)	Water Usage (L kg ⁻¹ produce)	Energy Requirements (kWh kg ⁻¹)	Initial Investment (₹ m ⁻²)	Maintenance Level
Traditional Soil Farming	4-12	300-500	1.5-4	4,000-8,500	Low
Rooftop Gardens	18-30	180-300	4-8	8,000-16,500	Medium
Hydroponic Systems	35-70	70-120	10-20	25,000-42,000	High
Rooftop Aquaponics	55-100	15-40	10-18	33,000-66,000	Medium-High
Vertical Aquaponics	90-180	10-25	18-30	50,000-1,00,000	High

Table 2: Economic Analysis of 500 m² Rooftop Aquaponics System

Financial Metric	Year 1	Year 3	Year 5	Long-term Average
Initial Investment (₹ Lakhs)	20-30	-	-	-
Annual Operating Costs (₹ Lakhs)	6-8	6-7	6-7	6.5
Vegetables production (kg)	5,000-6,000	6,000-7,000	6,500-7,500	6,200-6,500
Fish production (kg)	1,800-2,000	2,000-2,200	2,200-2,400	2,000-2,200
Gross Revenue (₹ Lakhs)	12-15	15-18	16-19	16
Net Profit (₹ Lakhs)	3-5	5-8	6-10	5-8
ROI (%)	10-15	15-20	20-25	~18

Smart monitoring technologies will allow remote monitor-ing of water quality parameters, feeding schedules of fishes, and environmental conditions, making these systems accessible to both commercial operators and community groups.

Economic Viability and Market Potential

Aquaponics systems are more economically viable now due to advancing technology and urban food prices, continued rising. Commercial rooftop farms reports yields of 3 to 5 times greater than traditional farming methods, all while using 90% less water. A 1,000 m² rooftop system is capable of producing between 15,000 to 25,000 kg of vegetables and 2,000 to 3,000 kg of fish annually. The financial model becomes especially appealing when additional revenue sources are factored in. In addition to food sales, successful rooftop farms earn income from educational tours, collaborations with local restaurants, community-supported agriculture (CSA) initiatives, and the sale of carbon credits.

Other market participants receive government funding, grants, and tax incentives aimed at encouraging urban farming and the adoption of green infrastructure.

Environmental Impact and Sustainability

Rooftop aquaponics systems deliver substantial environmental benefits that extend far beyond food production. Such systems are capable of mitigating the urban heat island effect with their evapotranspiration cooling and thermal mass features, which can reduce energy consumption by 10-30%. Their closed-loop irrigation systems eliminate the use of synthetic fertilizers and pesticides, mitigating agricultural pollutants. The carbon footprint associated with food grown on rooftops is 75 to 85% lower than that of produce grown in traditional farms when considering transport, packaging, and storage. Each rooftop farm has the potential to sequester 5 to 15 tons of CO₂, while producing oxygen like a small urban forest.

Additionally, these systems provide valuable rain water management, reducing urban flooding risks by capturing and slowly releasing rainwater.

Social Innovation and Community Building

Aside from their economic and technical advantages, rooftop aquaponics systems also act as drivers of social change and community participation. These units turn into open-air classrooms that cater to urban schoolchildren, specially concerning food systems, nutrition, and the environment. Community-based rooftop farms enhance neighborhood relationships while delivering economical, fresh produce to regions that lack adequate food retail outlets. The range of apprenticeship programs offered widens the scope of workforce development as the systems give rise to new job opportunities in urban agriculture, system upkeep, and food marketing. Cities across the globe are developing training programs for rooftop farm operators, providing access to entrepreneurship as well as skilled trades in the developing field of urban agriculture.

Future Prospects and Scaling Challenges

As outlined above, the multifaceted advantages of aquaponics on rooftops of urban structures is progressively being acknowledged by cities. The innovation of new technologies, such as artificial intelligence for system optimization, integration of renewable energy, and advanced automation, are further increasing cost effectiveness of these systems. Economical policy frameworks are adapting to encourage the practice of urban agricul-

ture by zoning, modifying building codes, providing subsidized funding, and other financial incentives. Despite these advancements, there is still a lack of adequate means to commercially advance aquaponics systems. Specialized knowledge is required for building them, but regulatory policies, structural restraints of model architecture and other corresponding factors hinder metastasis. Furthermore, the economic viability of this system rests crucially on the prevailing market situation, accessible sources of energy, and availability of marketable technical support systems.

Conclusion

Urban rooftop aquaponics is more than just a cutting-edge farming method; it's a fresh way of thinking about how our cities can become more self-sufficient, sustainable, and resilient. The analysis and economic forecasts show that these systems can effectively tackle urban food security while providing environmental and social benefits that reach far beyond their immediate surroundings. Cities like Singapore and Brooklyn are already leading the charge, demonstrating that rooftops can be spaces of productivity, profitability, and transformation. The key to success lies in ongoing technological advancements, supportive policies, and communities ready to adopt new ways of urban living. Those rooftops above us aren't just empty spaces; they hold incredible potential for building a more sustainable and food-secure future in our cities.

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Mushroom Cultivation: A Good Option for Agri-Business Development and Livelihood Diversification

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Abstract

The mushroom cultivation presents an excellent opportunity for agribusiness development and livelihood diversification. In addition to being a high-value, low-input agricultural product, mushrooms offer a profitable alternative for farmers and entrepreneurs looking to expand beyond traditional crops in an effort to increase profit margins. Due to the relatively short cultivation cycle and minimal space requirements, mushroom farming is an attractive option for both rural and urban settings alike due to its ability to generate income quickly. Additionally, the practice also utilizes agricultural waste as a substrate, making it possible to contribute to sustainable farming and to reducing waste. Increasing demand for mushrooms in the culinary, medicinal and nutritional markets further enhances the potential for agri-entrepreneurs to establish niche businesses and boost the local economy as mushroom cultivation continues to gain popularity. As a result of tapping into this emerging industry, individuals can cultivate resilient livelihoods as well as promote sustainable agricultural growth in their communities.

Introduction

Mushrooms are large, fleshy, spore bearing fruiting bodies of fungi from the basidiomycetes class, belonging to the agaricales order that lack chlorophyll. In nature, there are over 2,000 different types of edible mushrooms. Among edible mushrooms, only 35 species can be commercially grown, with 25 of these considered suitable for consumption. The most widely cultivated mushroom globally is *Agaricus bisporus*, followed by *Lentinus edodes* and various *Pleurotus* species (Rathore *et al.*, 2017). For centuries, mushrooms have been appreciated as a nutritious food source. They provide high-quality protein, vitamins and minerals. The protein found in mushrooms is greater than that in

most vegetables and is of superior quality. A fresh button mushroom contains 28-42.5 % crude protein on a dry weight basis, whose digestibility about 60-70%, 8.3-16.2% crude fiber, 59.4% carbohydrates and 3.1% fat. Unlike grains and other foods, mushrooms contain essential amino acid such as lysine and tryptophane. The world health organization has recommended mushrooms as a major source of protein for vegetarian countries. In addition to protein, mushrooms also contain a large amount of vitamin B₁ (8.9 mg), B₂ (3.7 mg) and vitamin C (26.5mg) (Mehta *et al.*, 2011). Mushrooms provide folic acid and vitamin B₁₂, which are typically absent in most of the vegetables, as well as an array of essential minerals, notably potassium and

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iron. About 35 calories of energy is obtained from per 100 gm of mushroom. Due to the very low amount of sugar (0.5%) and starch in mushrooms, it is considered as ideal diet for diabetic patients. Mushrooms increase blood circulation by controlling sugar and cholesterol. Compounds derived from button mushrooms are known to possess antifungal and antibacterial effects (Chang and Buswell, 1996).

Mushrooms are grown in most part of the world. Worldwide, China, US, Netherlands, and France are the leading producer of mushroom. In India, growing of mushroom is an alternative source of income for many farmers. As per National Horticulture Board, In India, Bihar was the leading producer (28 tonnes, which was 10.82% of the total mushroom production in the country) of mushroom during 2021-22 followed by Maharashtra (25.60 tonnes, 9.89%), Orissa (25 tonnes, 9.66%) and Haryana (21.20 tonnes, 8.19%).

Importance of Mushroom Cultivation: Mushrooms are a rich source of protein, vitamins, and bioactive compounds. They are highly valued for their medicinal benefits, including immune enhancement and cholesterol reduction (Chang and Wasser, 2012). Cultivating mushrooms contributes to food security, offers a nutritious diet, and addresses issues of unemployment by creating jobs in both rural and urban areas.

Nutritional and Medicinal Value: Mushrooms, especially species like *Agaricus bisporus* (button mushroom), *Pleurotus ostreatus* (oyster mushroom), and *Ganoderma lucidum* (reishi mushroom), are

packed with essential nutrients. They contain high levels of antioxidants, dietary fibre, and bioactive compounds that promote health and prevent diseases (Atila *et al.*, 2017).

Environmental Benefits: India generates approximately 600 million tonnes of agricultural, forestry, and food processing residues annually (Kumar and Simranjeet, 2022). While some residues are utilized as livestock feed, soil mulch, bio-manure, and for energy production, a significant portion remains unutilized and is burnt on fields, especially in states like Punjab, Haryana, and Uttar Pradesh (National Policy for Management of Crop Residues, 2014). Factors like labour shortages, high removal costs, and mechanized harvesting contribute to this practice, causing greenhouse gas emissions, soil degradation, and health issues. Promoting mushroom cultivation can help manage crop residues, as fungi utilize organic materials for growth, offering a sustainable solution.

Economic Potential in Agri-Business: The increasing global population, shrinking per capita arable land, rapid urbanization and industrialization, climate change and the growing demand for quality and functional foods have highlighted the importance of secondary agriculture and novel crops such as mushrooms. Mushroom cultivation presents a viable option for generating supplementary income. Depending on the availability of capital and labour, it can be undertaken on a large or small scale and may also serve as a part-time activity alongside primary farming practices. This cultivation method requires

relatively minimal space and investment while demanding low maintenance. With rising health awareness, consumers are increasingly incorporating nutritious food items, including mushrooms, into their diets as alternatives to staple cereals. The demand for mushrooms is particularly high in metropolitan areas such as Delhi and Chandigarh. Farmers from the northwestern hill states of India have significant potential to generate substantial income through mushroom production. White button mushrooms (*Agaricus bisporus*) dominate the sector, accounting for 80% of the total production of 14,732 tonnes in Himachal Pradesh (DMR, 2019). A study conducted by Kayastha *et al.* (2022) reported that farmers involved in mushroom cultivation in key districts of Himachal Pradesh achieved a profit of 84 paise for every rupee invested, reflecting an output-input ratio of 1.84:1. Similarly, an earlier investigation by Sharma *et al.* (2018) in the Shimla district of Himachal Pradesh recorded an output-input ratio of 1.63:1.

Employment Generation: Mushroom cultivation is labour intensive, creating employment in growing, harvesting, processing, and marketing. Women and marginalized groups can significantly benefit from this sector due to its low skill requirement and adaptability in household settings. The Northern Himalayas are rich in wild edible mushrooms, including species like *Coprinus comatus*, *Lactarius sanguifluus*, *Amanita fulva*, and *Morchella spp.* (gucchi mushrooms). Among these, gucchi mushrooms are highly valued, priced at ₹1200-1500 per

100 g. Their collection and export offer significant employment and income opportunities for hill farmers (Gilhotra *et al.*, 2023).

Value-Added Products: Fresh mushrooms serve as a versatile raw material for the production of various value-added products, including pickles, jams, sauces, candies, and chips. In contrast, dried mushrooms are utilized in the preparation of instant soup mixes, baked goods, papads, and nuggets (Ojha and Shukla, 2023). Additionally, the pharmaceutical industry's demand for mushrooms such as *Ganoderma lucidum* underscores their economic potential.

Livelihood Diversification: Mushroom farming is an ideal choice for livelihood diversification, especially for smallholder farmers. It integrates seamlessly with existing agricultural systems and provides year-round income. In regions with limited arable land, mushrooms can be cultivated vertically, maximizing space utilization. Mushroom cultivation is a low-cost and quick process, making it an ideal option for small-scale farmers seeking to diversify their income during the dry season. This practice is particularly advantageous when water scarcity hinders the growth of other crops, as mushrooms are grown indoors and require significantly less water. Additionally, it helps reduce farmers' vulnerability to unfavourable weather conditions (FAO, 2020).

Empowering Marginalized Communities: Mushroom farming has been identified as a profitable enterprise which can lead to integrate rural development by increasing the income and self-emp-

loyment (Aditya and Bhatia, 2020). Training programs and government initiatives have empowered marginalized communities to adopt mushroom farming. These initiatives help in income generation, enhancing resilience to economic shocks, and promoting social equity.

Climate Resilience: Mushrooms thrive in controlled environments, making them less susceptible to climatic variations. This makes mushroom cultivation a stable source of income amid unpredictable weather patterns caused by climate change.

Challenges and Solutions: Despite its potential, mushroom cultivation faces challenges such as lack of awareness, lack of marketing, inadequate infrastructure, climate change, Resources availability and pest management issues. Addressing these challenges through training, technological intervention and government support can unlock the full potential of this sector.

Role of Technology: Modern technologies like IoT-based monitoring systems and climate-controlled units can enhance productivity and reduce losses. Moreover, research and development in mushroom genetics can lead to higher yields and disease-resistant strains (Royse *et al.*, 2017).

Policy Support: Government policies promoting subsidies, credit facilities, and training programs can catalyse the growth of mushroom farming. Public-private partnerships (PPPs) can also play a pivotal role in creating a sustainable ecosystem for mushroom cultivation.

Conclusion

Mushroom cultivation stands out as a promising avenue for agri-business development and livelihood diversification. With its economic, nutritional, and environmental benefits, it has the potential to transform rural economies and contribute to sustainable development goals. By addressing existing challenges and leveraging modern technologies, this sector can unlock significant opportunities for farmers, entrepreneurs, and communities.

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Optimization of Micronutrient Formulations for Pulses

Bhagyaresha Gajbhiye and Yashwini Amrutkar

Abstract

Pulses including chickpeas, lentils and peas are a vital source of protein, fiber and essential micronutrients for millions of people worldwide. However, pulse production is often constrained by micronutrient deficiencies, which can lead to reduced yield, poor nutritional quality and decreased viability. Micronutrients are necessary substances that plants only use in trace amounts it has an impact on photosynthesis as well as other critical plant functions like respiration, protein synthesis, and reproduction. The application of micronutrients increased agricultural product yield and quality, protecting human and animal health through the use of feed enriched with plant materials. The availability of other necessary elements in balanced ratios for plants depends on each essential element performing its function in plant nutrition appropriately. When present in sufficient amounts, these tracer elements improve the physiological, biochemical and metabolic traits of healthy plant growth, whereas their absence encourages abnormal plant growth. Due to intensive cropping, erosion-related top soil loss, leaching-related micronutrient losses and liming of acid soils, the incidence of micronutrient deficiencies in crops has significantly increased in recent years. It is very essential to maintain micronutrient concentration in soil to sustain the production and productivity of pulses.

Introduction

Pulses are the backbone of Indian agriculture due to their significant role in human and animal nutrition, soil ameliorative properties, environmental sustainability and economic viability. India is the largest producer, processor, importer and consumer of pulses in the world with more than 12 major and minor pulses cultivated over 29-30 million ha. The country witnessed production of 26.05 million tonnes of pulses during 2022-23. Pulses are a vital source of protein and micronutrients for millions of people worldwide. Pulses are a low fat source of pro-

tein with high levels of protein and fibre. Pulses also contain important vitamins and minerals like iron, potassium and folate.

Micronutrients: Micronutrients are essential nutrient required by plant in small quantities for optimal growth, development and productivity. They play crucial role in various plant physiological processes, including photosynthesis, nutrient uptake and enzyme activity. Out of 17 nutrients established as essential for plant growth, eight are required in small quantities and therefor called micro nutrients, also known as oligo-nutrients, trace elements.

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They are Boron (B), Chlorine (Cl), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Zinc (Zn), Nickel (Ni).

Role of micronutrients in plants:

Boron: Essential of germination of pollen grains and growth of pollen tubes, Essential for seed and cell wall formation, Promotes maturity, Necessary for sugar translocation, Affects nitrogen and carbohydrate.

Chlorine: Interferes with P uptake, Enhances maturity of small grains, Increase the disease resistance, Help in the photolysis.

Copper: Catalyses several plant processes, Major function in reproductive stages, Indirect role in chlorophyll production. Increases sugar content, Improves flavour of fruits and vegetables.

Iron: Promotes formation of chlorophyll, Acts as an oxygen carrier, Reactions involving cell division and growth

Manganese: Functions as a part of certain enzyme systems, Aids in chlorophyll synthesis, Increases the availability of P and Ca.

Molybdenum: Required to form the enzyme “nitrate reductase” which reduces nitrates to ammonium in plant, Aids in the formation of nodules help for biological nitrogen fixation.

Zinc: Aids plant growth hormones and enzyme system, Necessary for chlorophyll production, Necessary for carbohydrate formation, Necessary for starch formation, Aids in seed formation.

Why micronutrients require for plant growth?

- ✓ Intensive cropping has removed measurable

amounts of macro and micro nutrients.

- ✓ Use of animal manures has decreased and use of high-analysis fertilizers.
- ✓ Top soil has been removed through erosion, land leveling, resulting in deficiency of certain micronutrients. More information is available on crop responses, availability of nutrients in various soils, soil testing and plant analysis.
- ✓ Increasing crop quality and nutritional value of today's crops.
- ✓ Use of poor irrigation water.
- ✓ Interaction effect of nutrients with each other.

Types of micronutrient formulation

There are several types of micronutrient formulations available including:-

Single-micronutrient formulations: Containing a single micronutrient, such as zinc or boron.

Multi-micronutrient formulation: Containing a blend of multiple micronutrients.

Chelated micronutrient formulations: Containing micronutrients chelated with organic molecules to enhance stability and bioavailability.

Foliar-applied micronutrient formulations: Designed for foliar application, providing a quick and efficient way to deliver micronutrients to plants.

Forms in which micronutrients are absorbed by plants

Cations		Anions	
Iron	Fe ²⁺ (Ferrous)	Boron	H ₃ BO ₃ (Boric acid), H ₂ BO ₃ ⁻
Manganese	Mn ²⁺ (Manganous)	Molybdenum	MoO ₄ ²⁻ (Molybdate)
Zinc	Zn ²⁺ (zinc ion)	Chlorine	Cl ⁻ (Chloride)
Copper	Cu ²⁺ (Cupric ion)		
Nickel	Ni ²⁺ (Nickel ion)		

Factors affecting micro nutrient availability

Soil pH: One of the most significant soil characteristics that influence the availability of nutrients is soil pH. With the exception of Mo, micronutrient availability decreases as pH rises. The availability of micronutrients is typically lower in calcareous and saline-alkaline soils with very high pH levels.

Organic matter: Micronutrient availability may be lessened in soils with low levels of organic matter (less than 2.0%). Micronutrient availability is frequently low in soils with very high levels of organic matter (greater than 30% organic matter to a depth of 30 cm).

Soil texture: Sandier soils do a much poorer job of holding water and nutrients than clays and organic soils. The sandy soil will lose its nutrients due to leaching. Higher clay content (fine texture) soils are less likely to lack plant-available micronutrients. Micronutrient deficiencies are more likely to occur in sandy soils (course texture).

Parent material and climate: Soils developed on flood plain alluvium largely from siliceous sandstone exhibited strikingly lower concentrations of Zn, Cu, Mn and Fe. The availability of nutrients in the soil will decrease if they come from simple parent material.

Micronutrients are required throughout the growth cycle



Methods to improve micro nutrient efficiency

Foliar application: It can supply nutrients to plants at crucial junctures in their development, quick response as compared to soil application. The amount of nutrients that plants need exceeds their normal capacity to absorb them. A high nutrient requirement growth stage was applied without the use of soil directly to the leaf surface, preventing losses or fixation. Although they cannot completely replace soil application, they can supplement soil fertilization. In contrast to soil application, crop response happens quickly.

Advantages of foliar application

- ✓ Application rates are much lower than for soil application.
- ✓ Uniform application is easily obtained.
- ✓ Response to the applied nutrient is almost immediate so deficiencies can be corrected during the growing season.
- ✓ Leaching losses are nil.
- ✓ Little residual effect.
- ✓ Quick absorption compared to soil application.

Application with mixed fertilizer

Incorporation during manufacturing: During the manufacturing process, the micro nutrients are combined with the major fertilizers.

Bulk blending with granular fertilizer: In available fertilizer grades during the blending process and during subsequent handling, nutrients may separate. By carefully balancing the particle sizes of the blend's NPK components and micronutrient sources, it can be reduced.

Coating granular fertilizer: Granular NPK fertilizers can be coated with powdered micro-nutrients to reduce the likelihood of segregation.

Fluid fertilizer: It is liquid solution containing essential micronutrients like iron, zinc, manganese, copper, boron and molybdenum.

Chelates: Chemical compound that contain micro-nutrient bound to organic molecules.

Micro encapsulation and low-solubility products

Micro encapsulation on micro nutrient produces tiny capsules (micrometer diameter) that have several nutritional. The capsulation of commercial fertilizers uses polymer films to protect the nutrients from rapid stabilization reactions in soil and control their release into the soil solution during plant growth.

Nano encapsulated micronutrients: Nano-ecapsulation is a technique that coats micronutrients with a material at the nano scale. The coated micronutrients are called nanocapsules.

Crops sensitive to micro nutrient deficiency

Boron	Copper	Iron	Manganese	Zinc
Alfaalfa	Corn	Sorghum	Wheat	Sorghum
Clover	Onion	Soybean	Oat	Dry bean
Cotton	Tomato	Bean	Corn	Cotton
Sugar beat	Alfa alfa	Dry beans	Soybean	Corn

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Congress Grass: A Silent Threat to Indian Agriculture

Alok Kumar

Abstract

Congress grass an invasive weed introduced to India in the 1950s, poses a significant threat to Indian agriculture. It spreads rapidly, competing with crops for resources and releasing allelopathic chemicals that hinder plant growth. The weed degrades soil quality, reduces crop yields, and harms livestock due to its toxicity. It also causes severe allergic reactions in humans. Despite various control efforts including mechanical, chemical, and biological methods its management remains challenging. This article highlights the origin, impact, and control strategies for Congress grass, emphasizing the urgent need for integrated weed management and public awareness to safeguard agricultural productivity.

Introduction

Congress grass, scientifically known as *Parthenium hysterophorus*, is one of the most aggressive and harmful invasive weeds in India. Commonly called “Congress ghaas” or “gajar ghaas,” this plant has had a significant negative impact on agriculture, biodiversity, and public health. Its history in India traces back to the mid-20th century and highlights how a small mistake in biosecurity can have long-term ecological consequences.



Origins and Introduction to India

Parthenium hysterophorus is native to the tropical and subtropical regions of North and South America. It was never a part of India’s natural flora. The plant made its way to the Indian subcontinent accidentally in the 1950s, specifically around 1955,

through contaminated wheat grains imported from the United States under the PL 480 food aid program. The contaminated wheat was distributed across various regions in India, including Maharashtra, Madhya Pradesh, and Delhi, where the weed found favorable conditions to grow and spread rapidly. Since Congress grass thrives in open, sunny areas with disturbed soil, it soon began to flourish along roadsides, railway tracks, barren lands, and eventually into agricultural fields and pastures.

Rapid Spread and Establishment

By the 1970s, Congress grass had spread to several states, including Karnataka, Tamil Nadu, Andhra Pradesh, and Uttar Pradesh. Its ability to produce a large number of seeds (up to 25,000 per plant), which remain viable for many years, made it extremely difficult to control. The weed has no natural enemies in India, which allowed it to grow

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unchecked. It quickly began to outcompete native vegetation, degrade pasturelands, and invade croplands, leading to serious agricultural and ecological consequences.

Biological Characteristics: Congress grass is a fast-growing, herbaceous plant that thrives in tropical and subtropical climates. It is characterized by finely divided, feathery leaves and small, white flowers. The plant produces a vast number of seeds up to 25,000 per plant which are dispersed by wind, water, and human activity, facilitating its rapid spread.

Impact on Agriculture

Reduction in Crop Yields: Congress grass competes aggressively with crops for sunlight, water, and nutrients. Its allelopathic properties where it releases chemicals that inhibit the growth of surrounding plants further exacerbate this competition. Studies have shown that the presence of Congress grass can lead to yield reductions of up to 40% in crops such as wheat, rice, maize, and pulses.

Decline in Forage Availability: The weed's spread in pastures and grazing lands reduces the availability of nutritious fodder for livestock. Cattle and other herbivores tend to avoid grazing on Congress grass due to its toxicity, leading to a decrease in milk production and overall livestock health.

Soil Degradation: The allelopathic chemicals released by Congress grass not only suppress the growth of neighboring plants but also affect soil microorganisms essential for soil health. This disruption can lead to soil degradation, making it less fertile and less suitable for crop cultivation.

Health Implications

Human Health Risks: Direct contact with Congress grass can cause allergic reactions in humans, including skin rashes, dermatitis, and respiratory issues such as asthma. The plant's pollen is also a known allergen, exacerbating seasonal allergies.

Livestock Health: Congress grass contains toxic compounds that can cause severe health problems in livestock. Consumption of the plant can lead to symptoms ranging from mild digestive disturbances to severe organ damage and, in extreme cases, death.

Environmental Consequences

Biodiversity Loss: The aggressive nature of Congress grass allows it to outcompete native plant species, leading to a reduction in biodiversity. This loss affects the entire ecosystem, including pollinators, herbivores, and other flora and fauna dependent on native plants.



Fig. 1: Biodiversity Loss in nearby area of Congress grass

Disruption of Ecosystems: In natural habitats such as forests and grasslands, the dominance of Congress grass can alter ecosystem dynamics. Its spread can change the composition of plant communities, affecting the animals that rely on them for food and shelter.

Control and Management Strategies

Manual Removal: Early detection and manual uprooting of Congress grass can be effective in preventing its spread. Farmers and landowners are advised to wear protective gloves and masks when handling the plant to avoid allergic reactions.

Chemical Control: Herbicides can be used to control Congress grass; however, their application must be managed carefully to avoid harm to surrounding crops and the environment. Selective herbicides that target only the weed are preferred.

Biological Control: Introducing natural predators or pathogens specific to Congress grass is a promising approach. For instance, the leaf beetle *Zygogramma bicolorata* has been used in some regions to feed on the weed, though its effectiveness can vary.

Public Awareness and Education: Raising awareness among farmers and the general public about the dangers of Congress grass is crucial. Programs such as the “*Parthenium* Awareness Week” organized by the Indian Council of Agricultural Research (ICAR) aim to educate communities on identification, prevention, and control measures.

Conclusion

Congress grass poses a multifaceted threat to Indian agriculture, impacting crop yields, livestock health, soil fertility, and biodiversity. Addressing this issue requires a concerted effort from farmers, researchers, and policymakers. Through integrated management strategies and increased public awareness, it is possible to mitigate the adverse effects of Congress grass and protect India's agricu-

ltural heritage.

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Application of Classification and Regression Tree (CART) in Agriculture

Manoj Kanti Debnath and Bharat Kumar Marmat

Abstract

Decision trees with binary splits are commonly built using the Classification and Regression Trees (CART) methodology. This approach recursively partitions the data into two nearly homogeneous child nodes by selecting a split point on a specific variable that maximizes the reduction in impurity typically measured by the sum of squared errors for regression or Gini impurity for classification. CART analysis a nonparametric method of identifying subgroups of a population whose members share common characteristics influencing the dependent variable. They are often compared to methods such as Random Forest, Support Vector Machines (SVM), and Neural Networks. CART faces key challenges including overfitting, instability, and limited scalability, despite its strengths in simplicity and interpretability.

Classification and Regression Tree (CART)

Introduction

Classification and Regression Tree (CART) analysis is a nonparametric method of identifying subgroups of a population whose members share common characteristics influencing the dependent variable. The output of CART resembles the branches of a tree on a multilevel structure. Generally, classification and regression trees start with a single node which contains the entire sample, called a root node or parent node and advances by applying split criteria at each non-leaf node (decision node) leading into homogeneous subsets. However, attaining pure homogeneous subsets is not possible. Therefore, the aim at each node is to select an attribute (response variable) and a split condition on that attribute that minimizes heterogeneity of class

labels, thereby leading into almost pure subsets. Based on the chosen splitting rule, the tree continues to grow within each child node by utilizing the remaining response variables. This is done to identify which response variable results in the most optimal split. The procedure continues through each branch of the tree until a stopping rule is reached. As a result, both child nodes become parent nodes to the two groups that it splits into. A terminal node is created when no further splits are made. Terminal nodes form mutually exclusive and exhaustive subgroups (Lemon *et al.*, 2003). The dependent can be either categorical (classification tree) or continuous (regression tree). Independent variables can be any of the continuous and categorical variables. In regression trees, the average value of the dependent variable is computed among individuals

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inside each node. Classification trees operate much like regression trees, except they aim to predict the class (discrete category), rather than a numerical number.

Classification tree

Classification trees categorize data into finite number of classes depending on the values of input variables. It is best suited for categorical data (Sharda *et al.*, 2014). While building the classification tree, the aim at each node is to choose the split conditions that divide the dataset into homogenous subsets. The “goodness of split criterion” was derived from the concept of impurity (Breiman *et al.*, 1984). In each split condition, impurity is measured mathematically and the split condition with the lowest impurity value is selected. GINI index, Entropy and information gain are the common splitting indices used to evaluate the goodness of a split.

Entropy: Entropy is the basis for information gain. The entropy of a dataset measures its impurity or randomness (Shannon, 1948). There is no impurity or randomness in a dataset if the observations of subsets are homogeneous. The entropy of a dataset would be zero if all observations of a subset belong to the same class. Entropy is calculated by multiplying the probability of each label by its logarithm. If L is a learning sample which is a dataset based on which the tree is constructed (Breiman *et al.*, 1984) with j different class labels, then,

$$\text{Entropy}(L) = - \sum_{i=1}^j p_i \log_2 p_i$$

Where, p_i is probability that an arbitrary input variable belongs to class i ($i=1, 2, \dots, j$).

The impurity/uncertainty/ mixing will be higher if the entropy is higher (Fan *et al.*, 2011).

Information Gain: Information gain is based on Entropy. It measures the reduction of uncertainty after splitting the set on a feature. The feature with highest information gain is the best feature to be selected for split.

$$\text{IG}(L, \text{Child}) = \text{Entropy}(\text{parent node}) - \sum_{i=1}^j w_i * \text{Entropy}(\text{child}_i)$$

Where, w_i is the ratio number of response variables present in the child nodes to the parent node.

Gini Index/Gini impurity: By splitting a class along one attribute, the GINI index determines the purity of that class. Best splits result in more pure subsets. If L is a learning dataset with j different class labels, GINI is defined (Sharda *et al.*, 2014) as

$$\text{Gini}(L) = 1 - \sum_{i=1}^j p_i^2$$

Regression Tree: In CART (Breiman *et al.*, 1984), Regression Trees are built by successively applying the feature (response variable) based splits by choosing the optimal feature (response variable) and optimal split value that would minimize the error of leaf nodes or child nodes. Ultimately splitting feature that attains the largest reduction in variance is chosen. A regression tree computes the average value of the dependent variable among the individuals inside each node. A regression tree is constructed by splitting nodes by maximizing the variance reduction at each step (*i.e.*, to maximize the decrease in variance at each split).

$$\text{Variance reduction} = \text{Variance (parent node)} - \sum_{i=1}^j w_i * \text{Variance (child}_i)$$

Where, w_i is the ratio of number of response variables present in the child nodes to the parent node.

Applications of CART Analysis

Healthcare: Disease diagnosis and prediction, Patient risk assessment, Medical image classification.

Finance: Credit risk analysis, Fraud detection, Stock market prediction.

Agriculture: Crop yield prediction, Soil quality assessment, Disease outbreak forecasting.

Engineering and Manufacturing: Quality control in production, Fault detection in mechanical systems, Predictive maintenance.

Comparative Analysis with Other Machine Learning Techniques

Classification and Regression Trees (CART) are widely appreciated in the machine learning community for their simplicity, transparency, and effectiveness in both classification and regression tasks. They are often compared to methods such as Random Forest, Support Vector Machines (SVM), and Neural Networks. This section explores: advantages of CART lies in its interpretability its decision-making process is easily understood and visualized, which makes it especially valuable in fields where explainability is critical, such as healthcare and finance. Being a non-parametric method, CART does not assume any specific data distribution, making it flexible across a wide range of applications. Additionally, CART performs implicit feature selection by choosing the most infor-

mative variables at each node, which helps in reducing dimensionality and highlighting key predictors. However, CART is not without its limitations. It is highly prone to overfitting, especially when the tree grows too deep and captures noise in the data instead of general patterns. This issue often necessitates pruning techniques to improve generalization. Moreover, CART models can be sensitive to small variations in the training data, leading to instability in the structure of the generated tree. When compared to more advanced ensemble techniques such as Random Forest and Gradient Boosting Trees, CART typically falls short in predictive performance. Random Forest, an ensemble of multiple decision trees, reduces variance and improves robustness by averaging results across many randomized trees. Gradient Boosting, on the other hand, sequentially builds trees to correct errors made by previous ones, often achieving superior accuracy. Nevertheless, while CART may not always match the performance of these ensemble methods or other complex models like Support Vector Machines and Neural Networks, its interpretability and straightforward implementation make it a foundational and valuable tool, particularly in scenarios where model transparency is a priority.

Case Studies on CART Implementation

This section presents real-world applications of CART in different domains with experimental results, illustrating its effectiveness in solving practical problems.

Challenges and Limitations of CART

- ✓ Data sparsity issues.
- ✓ Scalability concerns for large datasets.
- ✓ Interpretability trade-offs in deep trees.
- ✓ Overfitting prevention strategies.

Future Research Directions in CART

To overcome current limitations and expand its capabilities, future research in CART focuses on several promising areas:

- ✓ Integration with deep learning and hybrid models.
- ✓ Enhancements in pruning and optimization techniques.
- ✓ Advances in explainable AI for decision tree models.
- ✓ Real-time and streaming data applications.

Conclusion

The article examines the CART analysis is organized as a series of questions, the responses to which decide the following question if any. The ultimate outcome of these questions is a tree-like structure with terminal nodes when there are no more questions the CART is widely used in making Decision Trees through Classification and Regression. Decision Trees are widely used in data mining to create a model that predicts the value of a target based on the values of many input variables (or independent variables). The CART remains a fundamental method in predictive analytics due to its simplicity and interpretability. While it faces challenges such as overfitting and computational efficiency, ongoing research and hybrid approaches continue to enhance its applicability across diverse

fields.

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Importance of Micronutrients in Oil Palm

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Abstract

Oil palm (*Elaeis guineensis* Jacq.) is one of the most productive, high yielding vegetable oil crops, and it plays a pivotal role in meeting global vegetable oil demands. To maintain its high productivity, appropriate application of nutrients is essential, not only with respect to macronutrients but also micronutrients. Micronutrients, though required in trace amounts, but they play a crucial role in oil palm growth, development, and yield. This article elaborates on the role of individual micronutrients, symptoms of their deficiencies and toxicities, and effective strategies for micronutrient management in oil palm cultivation. With the increasing boom of oil palm agriculture, precise nutrient monitoring and sustainable fertilization practices must be adopted to ensure optimum plant health, economic productivity, and environmental sustainability.

Introduction

Oil Palm: The golden crop

Oil palm is a high-yielding tropical perennial crop native to West Africa but widely cultivated in Southeast Asia, particularly Malaysia and Indonesia, which together account for over 85% of global production (Corley and Tinker, 2015). In India oil palm is mainly cultivated in the areas of Andhra Pradesh, Telangana, Kerala, Karnataka, Tamil Nadu, Odisha, Gujarat and some parts of North eastern states. Two types of oil were obtained from oil palm viz., palm oil from the mesocarp and palm kernel oil from the seed. With oil yields of up to 4-6 tons ha⁻¹ annually, oil palm is the most productive vegetable oil crop globally (Fairhurst and Härdter, 2003).

Its oil is a crucial ingredient in food, cosmetics and biofuels.

Micronutrients: The silent supporters

Micronutrients are required in small quantities, yet their role is immense in plant growth. Elements such as boron (B), zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), molybdenum (Mo), chlorine (Cl), and nickel (Ni) contribute to processes like photosynthesis, enzyme activation, hormone regulation, and reproductive development (Fairhurst and Härdter, 2003). Deficiencies or toxicities of micronutrients lead to physiological disorders, stunted growth, poor oil yield, and susceptibility to diseases.

Micronutrient deficiencies in oil palm

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Table 1: List of essential micronutrients in oil palm and their importance

Micronutrient	Importance
Boron (B)	Critical for cell wall synthesis, pollen germination, fruit development. Promotes sugar transport and hormonal regulation.
Zinc (Zn)	Activates enzymes, regulates auxin synthesis, and stabilizes membrane structure. Important for growth hormones and internode elongation.
Iron (Fe)	Essential for chlorophyll synthesis, photosynthesis, and respiration.
Manganese (Mn)	Functions in photosynthesis, nitrogen assimilation, and antioxidant activity.
Copper (Cu)	Involved in lignin synthesis, electron transport, and protein metabolism. Enhances disease resistance.
Molybdenum (Mo)	Key for nitrate reduction and nitrogen fixation.
Chlorine (Cl)	Regulates osmotic balance and stomatal function. Aids in disease suppression.
Nickel (Ni)	Required for urease activity and nitrogen metabolism.

Table 2: Micronutrient toxicity symptoms, causes and control measures

Micronutrient	Toxicity Symptoms	Causes	Control Measures
Boron (B)	Leaf tip burn, marginal necrosis, chlorosis	Excessive B fertilizers or irrigation water	Reduce B input, apply gypsum
Zinc (Zn)	Chlorosis, Fe-deficiency-like symptoms	Overapplication, industrial contamination	Apply Fe chelates, lower Zn input
Iron (Fe)	Bronzing of leaves, root damage	Waterlogged acidic soils	Improve drainage, apply lime
Manganese (Mn)	Leaf necrotic spots, black root tips	Acidic soils, high Mn fertilization	Apply lime, reduce Mn inputs
Copper (Cu)	Root growth inhibition, leaf cupping	Excessive Cu from fungicides	Use organic matter, reduce Cu sprays
Molybdenum (Mo)	Leaf margin burn, yellowing	Rare; usually excessive foliar Mo sprays	Reduce Mo input, monitor soil Mo levels
Chlorine (Cl)	Leaf scorch, salt stress symptoms	Overuse of MOP, saline water	Leach soil with water, switch to SOP
Nickel (Ni)	Growth retardation, leaf burn	Industrial or fertilizer contamination	Avoid overapplication, enhance soil aeration

Boron (B) deficiency

Symptoms: Hook-shaped or crumpled young leaves, barren inflorescences, short internodes, hard fruit shells.

Impact: Poor pollination, malformed fruit bunches, reduced oil yield.

Causes: Leaching in acidic soils, sandy textures, high rainfall areas.

Control measures

- ✓ Apply borax or solubor (1-2 kg palm⁻¹ year⁻¹) based on soil test.
- ✓ Use slow-release boron fertilizers in high-rainfall zones.
- ✓ Foliar sprays (0.2% boric acid) during peak growth stages.

Zinc (Zn) deficiency

Symptoms: Small, narrow leaves with interveinal chlorosis, rosette appearance, stunted fronds.

Impact: Reduced leaf expansion and chlorophyll content.

Causes: High phosphorus levels, alkaline soils.

Control measures

- ✓ Soil application of zinc sulfate (ZnSO₄) @ 50-100 g palm⁻¹.
- ✓ Foliar sprays (0.5% ZnSO₄ + 0.25% lime).
- ✓ Maintain balanced P levels.

Iron (Fe) deficiency

Symptoms: Uniform interveinal chlorosis in young leaves, white appearance in severe cases.

Impact: Impaired photosynthesis and growth.

Causes: Waterlogging, high pH soils.

Control measures

- ✓ Use chelated iron (Fe-EDDHA) for foliar application.
- ✓ Improve drainage and avoid over liming.

Manganese (Mn) deficiency

Symptoms: Interveinal chlorosis with small necrotic spots, mostly in young fronds.

Impact: Weakened photosynthetic efficiency.

Causes: High pH soils, excess Fe/Zn, organic matter buildup.

Control measures

- ✓ Soil or foliar application of MnSO_4 (50-100 g palm^{-1}).
- ✓ Maintain pH below 6.5 using acidifiers if needed.

Copper (Cu) deficiency

Symptoms: Leaf tip necrosis, bronzing, and frond wilting.

Impact: Weak leaf tissues, poor fruit development.

Causes: Organic matter binding, excessive P.

Control measures

- ✓ Soil or foliar application of CuSO_4 (30-50 g palm^{-1}).
- ✓ Avoid excessive use of organic manure without balancing Cu.

Molybdenum (Mo) deficiency

Symptoms: Pale, rolled leaflets, poor nitrogen metabolism.

Impact: Reduced growth and poor nitrate assimilation.

Causes: Acidic soils.

Control measures

- ✓ Application of sodium molybdate (10-15 g palm^{-1}).
- ✓ Lime acidic soils to pH 6.5-7.0.

Chlorine (Cl) deficiency

Symptoms: Wilting, chlorosis, increased disease incidence.

Impact: Reduced salt tolerance and photosynthetic rate.

Control measures

- ✓ Use potassium chloride (MOP) as Cl source.
- ✓ Apply based on leaf analysis.

Nickel (Ni) deficiency

Symptoms: Accumulation of urea in tissues, necrotic tips.

Impact: Affects urease activity and nitrogen metabolism.

Control measures: Foliar application of nickel sulfate (5-10 g palm^{-1}).

Micronutrient toxicity in oil palm

Excessive application of micronutrients will lead to micronutrient toxicity in oil palm. There are devastating effects of micronutrient toxicity, so it is very much necessary to identify micronutrient toxicity.

Micronutrient management in oil palm: From nursery to maturity

Nursery stage

- ✓ Soilless media or sterilized loam should be supplemented with micronutrient-enriched foliar sprays.
- ✓ Chelated forms (Fe-EDDHA, Zn-EDTA) are effective.

- ✓ Monitor seedlings for early deficiency symptoms and treat them properly.

Field establishment

- ✓ Conduct soil testing before transplanting.
- ✓ Apply basal micronutrients based on requirement.
- ✓ Apply organic amendments (e.g., composted empty fruit bunches) to enhance micronutrient retention.

Maintenance phase

- ✓ Conduct leaf analysis (frond 9 in palms of age below 3 years and 17 in palms of above 3 years) annually to monitor nutrient status.
- ✓ Apply micronutrients as part of composite NPK + micronutrient formulations or separate foliar sprays.
- ✓ Split applications of B and Zn improve uptake and reduce leaching.
- ✓ Monitor soil pH and use lime or gypsum as needed.

Environmental considerations

- ✓ Avoid over-application to prevent runoff into waterways.
- ✓ Practice site-specific nutrient management (SSNM) using decision support tools.

Conclusion

Micronutrients, though required in minute quantities, are very much needed for the robust growth, productivity, and sustainability of oil palm. Deficiencies can drastically reduce oil yield and quality, while toxicities may damage physiological functions. A holistic nutrient management plan,

comprising site-specific recommendations, balanced fertilization, regular monitoring, and integration of organic sources can ensure optimal micronutrient supply. As global demand for palm oil grows, precision in nutrient management will determine the future profitability and environmental sustainability of oil palm cultivation.

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Bamboo: A Renewable Resource

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Abstract

Bamboo, frequently referred to as the “green gold,” is an extraordinary plant renowned for its adaptability, sustainability, and expeditious growth. bamboo, (subfamily Bambusoideae), approximately 87 genera and over 1,500 species of bamboo exist, with roughly 100 species comprising those of economic importance. Bamboo grows mainly in warm regions, including tropical and subtropical areas, and some temperate places. The highest variety and number of bamboo species are found in East and Southeast Asia, as well as on islands in the Indian and Pacific Oceans. A few types of bamboo, specifically from the genus *Arundinaria*, are found in the southern United States, where they grow in thick clusters along rivers and in wetlands. Particularly in industries like pulp and paper, bamboo's potential as a sustainable alternative to wood, emphasizing its benefits for environmental conservation and economic development. Bamboo is noted for its abundance, renewability, and strength, making it an attractive material for various commercial applications. The bamboo is an extraordinary and unique tree of our planet because it is the fastest growing tree and is annually renewable and harvestable if managed intensively (Scurlock, 2000). Bamboo is a productive, sustainable and versatile plant and one of the important Non-Wood Forest Products (NWFP), providing food, raw material and shelter and found in a wide variety of climatic and edaphic conditions.

Introduction

Bamboo is one of the commercially cultivated crops in India and it is also considered as ‘a poor man’s timber’. India is the second largest producer of Bamboo in the world after China. Bamboo is a fast-growing woody plant which is a renewable source of fuel which has a heating value comparable to that of timber from trees. Bamboo is a flowering, permanent and evergreen plant, which belongs to the grass family of Poaceae. Its natural growth ranges

from 47° S to 50° 30' N latitude and from sea level to 4,300 meters in altitude, primarily in mesic to wet forest areas, though some species also grow in grasslands. Bamboo is a renewable material that decomposes naturally at the end of its life, making it environmentally friendly according to Life Cycle Assessment studies. Its use in construction supports sustainable development.

Products of Bamboo: Various species of bamboo provide a wide range of products, including, strong

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and durable bamboo can be used for structural purposes, flooring, trim, and ply bamboo, which is similar to plywood. Light and sturdy bamboo is ideal for crafts, handicrafts, and furniture making. Bamboo fibers are used to create items like paneling and baskets. Bamboo pulp is utilized to produce paper and other fiber products. Bamboo serves as raw materials for creating fencing, tools, rafts, trellises, and water pipes. Bamboo provides food for livestock such as cattle, sheep, and goats. Edible bamboo shoots are consumed as food. Bamboo has applications in medicine. Bamboo can enhance landscapes or be used as cut foliage in decorations. Large stems can be made into planks for construction and rafts, while both large and small stems are used to create scaffolding. They can also be split for making buckets, pipes, furniture, flooring, walking sticks, fishing poles, garden stakes, and various utensils. Additionally, some bamboo species are grown as ornamental plants in gardens. The silica found in bamboo joints, known as tabasheer, has medicinal uses.

Chemical Composition of Bamboo: Bamboo is primarily composed of three main substances: cellulose, hemicelluloses, and lignin, which together make up about 90% of its total mass. In addition to these major components, bamboo contains minor substances such as pigments, tannins, proteins, fats, pectin, and ash, as well as resins, waxes, and inorganic salts. These various components play significant roles in the plant's physiological functions and are located in the cell cavities or specialized

structures within the bamboo. While bamboo's chemical makeup is similar to that of wood, it has a higher proportion of these minor components.

Structure: The structure of bamboo, which determines its ultimate mechanical qualities, is described in the anatomy of bamboo. The above-ground stem, which may be straight or bent. The stem base, which is the lower portion of the stem that reaches the ground. The stem petiole, which is composed of several short sections and is the lowest part of the stem. The culm, which is the main stem of a plant, is made up of two key parts: internodes and nodes (also called diaphragms). Nodes are areas where cells are oriented either across or parallel to the stem, while internodes are made up of cells that run along the length of the stem. Most culms are hollow, like tubes, and the thickness of the stem's wall defines the space between the inner and outer surfaces. However, some plant species may have solid stems instead of hollow ones.

Bamboo-Based Agroforestry: Agroforestry innovations on degraded lands have been prioritized for promoting environmental sustainability, advancing food and fodder security, and achieving United Nations Sustainable Development Goals. Recently, there has been increasing interest in their role in soil health improvement, biomass production, and climate change mitigation, contribution of bamboo-based agroforestry for enhancing provisioning ecosystem services is very limited. Bamboo can function similarly to trees in ecosystems and is ideal for agroforestry. It offers several benefits compared

to trees, including a quicker growth cycle from planting to harvest, the capacity to provide sustainable building materials and food for many years, and a greater versatility in use. Due to its adaptability and diverse applications, bamboo can play a crucial role in various agroforestry systems. Bamboo finds use in many other items such as paper, musical instruments, weaponry, handicrafts and boats. It has a central role in many folk tales and traditional practices. Grazing farm animals are sometimes fed bamboo fodder, known to be as nutritious as other common fodder grasses.

Applications of Bamboo: Bamboo has many uses because of its special qualities. One big use is in building. Bamboo can be used to make houses, bridges, and other structures. It is very strong for its weight which makes it good for parts that hold buildings up. Also, bamboo is often used to make furniture and art things because it looks nice and lasts a long time. Another important use is in the paper industry, where bamboo can be made into pulp for different paper products. Bamboo grows fast and gives a lot which makes it renewable and can be used again and again (Clark *et al.*, 2015). Also, bamboo helps with erosion, water cleaning, and making energy.

Soil Conservation: Bamboo's strong and extensive root system helps prevent soil erosion and improves soil structure, making it beneficial for areas at risk of erosion.

Carbon Sequestration: Bamboo grows quickly and produces a lot of biomasses, allowing it to absorb

carbon dioxide from the atmosphere effectively, which helps combat climate change.

Biodiversity Enhancement: Bamboo agroforestry creates habitats and food sources for various plant and animal species, supporting biodiversity and strengthening ecosystem resilience.

Economic Opportunities: Growing bamboo provides farmers with multiple income sources, such as selling bamboo shoots, timber, and handicrafts, which can improve their livelihoods and economic stability.

Conclusion

For a long time, bamboo has been “poor man’s timber”, so it became the choice of material for most low-cost or cost-effective housing. Bamboo grows quickly and is in high demand, but its sustainability is under threat. We need to closely evaluate how renewable it is to meet both traditional and modern needs. Bamboo can thrive in almost any climate and can be harvested in 3 to 5 years, making it more versatile than many other woody plants. Despite being used for thousands of years, bamboo has not been depleted. However, we must explore advanced methods to use bamboo more effectively to ensure its long-term sustainability.

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Biocontrol Heroes: Harnessing Beneficial Microbes to Fight Plant Diseases

Abhinav Thakur, Sweta and Shiv Kumar Saini

Abstract

The antagonistic mechanisms of bacterial and fungal biocontrol agents include the production of antibiotics, siderophores, secretion of enzymes, competition for nutrients, and promotion of plant growth by rhizosphere microorganisms. Traditionally, synthetic pesticides have been the primary method for controlling diseases caused by phytopathogenic microorganisms. However, their widespread and improper use in intensive agriculture has led to several issues, including environmental pollution, significant pesticide residues in agricultural products, and the development of resistance among phytopathogens. Furthermore, these chemicals negatively affect beneficial soil microorganisms that contribute to soil fertility. Safe, eco-friendly, and cost-effective alternatives to synthetic pesticides are needed. Biocontrol agents offer an effective solution for managing plant diseases like nematodes, fungi, and bacteria. Nowadays, biocontrol agents play a significant role in agriculture. They are cost-effective, environmentally friendly, and offer a sustainable way to inhibit the growth of pathogenic microorganisms.

Introduction

The intensive application of chemical fertilizers and prolonged agricultural practices have, to some degree, led to the degradation of soil quality. These practices have altered the soil's physical and chemical properties, disrupted the structure of microbial communities, and ultimately hindered the sustainable advancement of agriculture. In response, organic farming has emerged as a viable and sustainable alternative to conventional methods, largely fueled by growing environmental awareness and increased consumer preference for healthier food. Microbiology plays a pivotal role in organic farming, where microorganisms contribute significantly to nutrient recycling, maintaining soil health, and controlling pests. The application of microbial

inoculants is influenced by soil characteristics and includes benefits such as supplying essential micro-nutrients via natural nitrogen fixation, producing plant hormones and antimicrobial compounds, and enhancing the availability of key nutrients like potassium and phosphorus. Key plant-beneficial microbes include *Rhizobium*, *Azospirillum*, *Trichoderma*, *Pseudomonas*, *Acinetobacter*, *Bacillus* and *Mycorrhizal fungi*. Numerous studies have demonstrated that microorganisms positively impact soil by fostering the growth of plant growth-promoting microbes (PGPMs), producing siderophores and competing with pathogens for nutrients and space. These activities not only prevent soil-borne diseases but also enrich soil fertility, ultimately boosting agricultural productivity.

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In the context of plant disease management, biological control refers to the reduction or inhibition of diseases or their causative pathogens through the use of one or more antagonistic organisms, either by direct interaction or indirect mechanisms. The growing emphasis on sustainable agriculture with minimal environmental impact has elevated interest in biocontrol, leading to significant scientific, economic, and political discourse around its implementation. As a result, some countries have adopted proactive strategies that have successfully reduced pesticide usage by up to 50%. Recent progress in biological control has been especially encouraging with the use of antagonistic biocontrol agents (BCAs) such as species of *Pseudomonas*, *Bacillus*, *Burkholderia*, and *Trichoderma*. These microbes have shown effectiveness against a variety of foliar and soil-borne plant pathogens, including *Agrobacterium radiobacter* var. *radiobacter*, *Erwinia* spp., *Fusarium* spp., *Rhizoctonia solani*, *Phytophthora* spp., and *Pythium* spp. Moreover, other BCAs have also demonstrated broad-spectrum antagonistic activity. These include fungi such as *Aspergillus*, *Beauveria*, *Fusarium*, *Penicillium*, and *Phoma* species, and bacterial genera like *Paenibacillus*, *Pantoea*, *Serratia*, *Burkholderia*, and *Streptomyces*. In addition to their disease-suppressing capabilities, many of these microbes also promote plant growth directly.

Microbes as a Bio-Control Agents: Micro-organisms such as bacteria, fungi, and viruses serve as effective bio-control agents by targeting specific

pests or pathogens while minimizing harm to beneficial organisms. These microbes function through a range of biological mechanisms, including competition for nutrients and space, parasitism, production of inhibitory substances (antibiosis), and the activation of host plant defense systems. Notable examples of microbial bio-control agents include *Bacillus thuringiensis* (Bt), which is widely used for insect pest management; species of *Trichoderma*, known for suppressing fungal diseases; and nucleopolyhedroviruses, employed in the control of lepidopteran insect pests (Tariq *et al.*, 2020).

Mechanisms of Biological Control

The effectiveness of biological control relies on four main mechanisms:

Parasitism: The biocontrol agent (antagonist) parasitizes the pathogen by directly attacking it.

Antibiosis: The antagonist secretes antibiotic metabolites that are harmful to the pathogen.

Competition: The biocontrol agent competes with pathogens for nutrients or space, suppressing pathogen growth.

Lysis: The antagonist produces cell wall-degrading enzymes, leading to the death and breakdown of the pathogen.

Parasitism and Lysis

In biocontrol, some organisms exhibit parasitism by directly attacking and feeding on plant pathogens. For instance, *Trichoderma viride* parasitizes pathogens by coiling around their hyphae. Additionally, various bacteria and fungi secrete hydrolytic enzymes that degrade the cell walls of

pathogens, leading to lysis. Some examples include:

Bacillus spp.: Cause hyphal lysis of *Gaeumannomyces graminis*.

Serratia marcescens: Produces chitinolytic enzymes that lead to cell wall lysis of *Sclerotium rolfsii*.

Trichoderma spp.: Secrete chitinases and β -1,3-glucanases, which lyse the cell wall of *Rhizoctonia solani*.

Antibiosis

In antibiosis, the biocontrol agent produces antibiotic compounds that inhibit or suppress the growth of plant pathogens. For example: Phenazine-1-carboxylic acid, produced by *Pseudomonas fluorescens*, plays a significant role in suppressing take-all disease of wheat caused by *Gaeumannomyces graminis*.

Competition

In competition-based biocontrol, beneficial bacteria and fungi compete with plant pathogens for nutrients and essential elements, such as iron and carbon sources. This competitive exclusion helps suppress or displace the pathogens, preventing disease. Examples:

- ✓ Nutrient competition between *Pythium aphanidermatum*, *P. ultimum*, and beneficial bacteria helps suppress damping-off disease in cucumbers.
- ✓ *Pseudomonas fluorescens* produces fluorescent siderophores, such as pseudobactin and pyoverdine, which chelate iron (Fe) in the soil. This deprives the pathogen of essential iron,

thereby inhibiting its growth.

Advantages of Microbial Bio-Control

Minimized Environmental Impact: Microbial bio-control agents are typically regarded as environmentally safe, producing fewer residual effects than conventional chemical pesticides.

Specificity toward Target Pests: These microorganisms can be naturally selected or genetically modified to act against particular pest species, thereby reducing unintended effects on non-target organisms.

Lower Risk of Resistance: Repeated use of chemical pesticides often leads to the evolution of resistant pest strains. In contrast, microbial agents operate through different biological mechanisms, which helps decrease the potential for resistance development.

Suitability for Integrated Pest Management

(IPM): Microbial bio-control methods integrate effectively into IPM programs, supporting comprehensive and sustainable pest control strategies.

Methods for Utilizing Beneficial Microorganisms

Beneficial microorganisms, including certain bacteria and fungi, can function as biocontrol agents to help manage plant diseases. These microbes combat plant pathogens by outcompeting them for essential nutrients, releasing antimicrobial substances and triggering systemic resistance within the host plant. Notable examples include bacterial genera such as *Pseudomonas*, *Bacillus*, and *Rhizobiaceae*, along with fungal species like *Trichoderma* and

Piriformospora. Rather than depending on a single microbial species, using a synergistic mix or consortium of beneficial microbes can be more effective. Such microbial communities can stabilize the rhizosphere environment, leading to more consistent and efficient pathogen suppression. Combining multiple microorganisms tends to offer wider-ranging protection and improved disease resistance. Another promising approach involves leveraging plant-microbe interactions to enhance defense against soil-borne pathogens. Plants can attract helpful microbes to their root zone, which in turn boosts their health and resilience. These interactions typically involve priming the plant's immune responses, secreting antibiotic substances, and competing with harmful microbes for space and resources. Modifying the microbial makeup of the rhizosphere the soil region surrounding plant roots can significantly improve plant defense and overall crop productivity. This can be achieved by introducing specific beneficial microbes that enhance both plant health and resistance to diseases (Heimpel and Mills, 2017).

Recent advancements in molecular biology, including genomics and multi-omics technologies, have deepened our understanding of the complex molecular interactions between plants and beneficial microbes.

Conclusion

Beneficial microbes present a transformative strategy for sustainable plant health management. Understanding plant-microbe interactions and over-

coming practical challenges can help realize their full potential in creating resilient and eco-friendly agricultural systems. The use of microbial consortia, integrated approaches, and advances in molecular biology may lead to more effective and sustainable solutions for plant health management. Regulatory frameworks will remain key in guiding the development and adoption of biological control strategies.

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Blue Roses: Mystery and Wonder

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Abstract

The blue rose has long captured human imagination, symbolizing the unattainable, the mysterious, and the fantastical. While roses naturally bloom in red, white, yellow, and pink, the absence of a true blue rose in nature has intrigued botanists, artists, and romantics alike. This article delves into the historical symbolism, botanical challenges, scientific breakthroughs, cultural representations, and modern-day developments related to blue roses. Through a journey spanning mythology, genetics, biotechnology, and global commerce, we explore how the quest for a blue rose reflects both our limitations and our ingenuity. Despite decades of effort, true blue pigmentation in roses remains elusive, keeping the allure of the blue rose intact. Yet, advancements in genetic engineering offer promising pathways, opening a new chapter in the story of this floral enigma.

Introduction: The Color that Nature Denied

The rose is one of the most cherished flowers worldwide, symbolizing love, passion, and beauty. Yet, among all the vibrant hues it flaunts, there is one color nature has never granted it: blue. This absence has not only ignited myths and inspired poetry but has also spurred decades of scientific exploration. The idea of a blue rose unattainable, ethereal, and otherworldly has been a muse for artists and a holy grail for horticulturists.

Historical Background and Symbolism

Blue roses have often appeared in literature and folklore as emblems of the impossible. In ancient Chinese tales, a suitor was tasked with bringing a blue rose to win a princess's hand knowing it was a demand he could not fulfill.

In the Victorian language of flowers (floriography), a blue rose stood for mystery and a love that could never be. Writers and poets, including Rudyard Kipling and Tennessee Williams, used blue roses to reflect themes of longing, sadness, or unattainable desires. In *The Glass Menagerie*, Laura's nickname "Blue Roses" highlights her fragility and distance from societal norms.

The Science of Rose Coloration

Roses naturally come in a range of colors due to the presence of pigments like anthocyanins (for reds and purples), carotenoids (for yellows), and flavonoids. The pigment delphinidin is responsible for true blue coloration in flowers such as violets and pansies. However, roses lack the specific gene pathways needed to produce delphinidin, making a

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true blue rose biologically impossible through traditional breeding. Attempts to create blue roses by crossbreeding or dyeing white roses date back to the 19th century. While these methods resulted in lavender or purple shades, they never achieved a true blue.

The Genetic Breakthrough: Engineering Blue Roses

In the early 2000s, Japanese company Suntory, in collaboration with Australian biotechnology firm Florigene, genetically engineered a rose containing the delphinidin gene from a blue pansy. After years of research, they introduced the first genetically modified “blue rose” in 2004 and began commercial sales in 2009. However, the resulting flower named “Applause” was more lilac or mauve than blue. Still, it marked a major leap forward and demonstrated the power of synthetic biology in floriculture.

Cultural and Commercial Impact

The debut of a genetically modified blue rose made global headlines. In Japan, where the flower market holds cultural and emotional value, the blue rose was marketed as a symbol of miracle and dreams come true. Prices were steep initially over \$30 per stem yet the novelty found eager buyers. In the West, blue roses remain a curiosity, frequently dyed or spray-painted for events or romantic gestures. Their rarity and symbolism make them ideal for weddings, fantasy-themed events, and high-end floral arrangements.

The Quest Continues: Are We Close to a True

Blue?

Despite scientific progress, the holygrail remains elusive. Even genetically modified blue roses contain only about 95% delphinidin, with the remaining 5% of other pigments shifting the final color toward purple. Achieving a “sky blue” rose would require suppressing all competing pigments a task far more complex than inserting a single gene. Researchers are now exploring CRISPR and other gene-editing tools to refine pigment pathways. Synthetic biology might soon allow for a completely new biosynthetic route that replicates the blueness seen in hydrangeas or butterfly peas.

Ethical Concerns and Public Perception

As with any genetically modified organism, blue roses raise questions around ecological safety, consumer acceptance, and biodiversity. Critics argue that genetically engineered flowers serve commercial purposes more than ecological or humanitarian ones. Public reaction varies by region. In Japan and Australia, the response has been largely positive. In Europe, where GMOs face stricter regulation and public skepticism, commercial acceptance is still a distant dream.

Blue Roses in Modern Media and Pop Culture

Blue roses continue to fascinate creators in film, anime, music, and digital art. In David Lynch’s *Twin Peaks*, blue roses symbolize supernatural phenomena. In K-pop and J-pop, blue roses often feature in lyrics and visuals to represent purity, desire, or sorrow. They are also popular motifs in tattoos and jewelry, where the symbolism remains

open to interpretation ranging from impossible love to spiritual transformation.

DIY and Artificial Blue Roses: Because true blue roses are rare and costly, florists often create faux versions by dyeing white roses. This method, though temporary, creates stunning results and is widely used in weddings and themed events. YouTube tutorials and TikTok videos on DIY blue roses have millions of views, showing how the flower continues to captivate the younger generation.

Blue Roses and Mental Health Symbolism: In recent years, the blue rose has become a symbol of neurodiversity, introversion, and mental health awareness. As a representation of the misunderstood or unseen, it resonates with communities seeking uniqueness and validation. Blue rose imagery is now part of advocacy campaigns and mindfulness tools.

Future Prospects: Beyond Blue Roses

The quest for the blue rose mirrors humanity's broader desire to transcend limitations. While we may not yet have a perfect blue rose, the research paves the way for customized flowers roses that change color, glow in the dark, or even release tailored scents. The blue rose, in this light, becomes a stepping stone toward the future of synthetic floriculture.

Conclusion

The blue rose is more than a floral oddity it is a mirror of our dreams, a testament to innovation, and a symbol of what lies just beyond reach. Its journey from myth to lab-grown marvel reveals the intersections of culture, science, and desire.

As we move forward with biotechnology, perhaps one day we will hold in our hands a sky-blue rose, born not of fantasy but of brilliant science.

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Post-Harvest Mechanization: Reducing Losses and Improving Shelf Life

Rakshitha R. Shekar, Mohammad Rafeek N. Nadaf, Syed Mazar Ali, Arshad Khayum and Mahantesh Sanant Chigari

Abstract

Agriculture plays a central role in ensuring global food security. However, one of the biggest challenges that continues to plague the sector is post-harvest loss. Despite abundant agricultural production, millions of tonnes of food are lost every year due to inefficient post-harvest handling, poor storage, and outdated logistics systems. This not only affects farmer incomes but also contributes to hunger, food inflation, and resource wastage. Post-harvest mechanization has emerged as a powerful solution to address these challenges. By introducing machinery and technology into the stages of harvesting, sorting, grading, drying, packaging, and storage, mechanization helps reduce physical damage, microbial spoilage, and handling inefficiencies. From automatic grading machines to cold storage units and AI-driven supply chain platforms, innovations are transforming the way food is preserved and moved. This article explores the scope, benefits, and challenges of post-harvest mechanization. It highlights global and local success stories and outlines the policy framework necessary to make these technologies accessible to small and marginal farmers. With the right investment and support, post-harvest mechanization can drastically reduce losses and improve shelf life, creating a more resilient, efficient and sustainable food system.

Introduction

In a world where nearly 800 million people face chronic hunger, it's alarming that one-third of all food produced is lost or wasted. Much of this happens after harvesting, during handling, processing, storage, and transportation. These losses not only reduce the availability of food but also represent wasted labour, water, land, and capital.

In India alone, post-harvest losses in cereals, fruits, and vegetables amount to over ₹90,000 crores annually (ICAR-CIPHET, 2019). Mechanization can be a game-changer. Traditionally, post-harvest activities have been manual and labour-intensive, leading to inefficiencies. With machines, farmers and producers can reduce spoilage, maintain quality, and reach markets faster and more safely.

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From harvesters and dryers to cold storage and intelligent logistics systems, mechanization offers a holistic solution to the crisis of food loss.

Understanding Post-Harvest Losses

Post-harvest losses are categorized into two types:

Quantitative losses: These include actual reductions in weight or volume due to spillage, spoilage, or breakage.

Qualitative losses: These involve deterioration in taste, colour, nutritional value, or market acceptability due to spoilage, pests, and microbial contamination.

Several factors contribute to these losses:

- ✓ Delayed harvesting
- ✓ Rough handling
- ✓ Inadequate drying
- ✓ Lack of proper packaging
- ✓ Absence of temperature-controlled storage and transport

For perishable commodities like tomatoes, bananas, and leafy greens, even a small delay in post-harvest handling can lead to major spoilage. A comprehensive approach to mechanization at every stage is crucial to addressing these issues.

Stages of Post-Harvest Handling

Post-harvest management involves multiple stages, each with potential points of loss:

Harvesting: Manual harvesting can result in physical damage to produce.

Sorting and Grading: Quality differentiation is essential for market pricing and storage planning.

Cleaning and Drying: Removes dust, microbes, and

excess moisture.

Packaging: Proper packaging prevents crushing, microbial attack, and moisture absorption.

Storage: Temperature, humidity, and airflow control are vital for longevity.

Transportation: Efficient logistics ensure timely delivery with minimal damage.

Mechanization at each of these points enhances speed, efficiency, and product quality.

Mechanization at Each Stage

Harvesting: Modern tools like pneumatic clippers, automatic harvesters, and conveyor harvesters reduce labour dependency and minimize physical damage.

Sorting and Grading: Machines with cameras and sensors can sort produce based on size, color, and ripeness. For example, optical sorters use AI to detect defects and ensure uniformity in packaging.

Cleaning and Drying: Mechanical washers, vibratory screens, and tunnel dryers improve hygiene and reduce microbial load. Moisture meters and automatic drying machines maintain consistency.

Packaging: Vacuum sealers, modified atmosphere packaging (MAP), and automated bagging machines help extend shelf life by reducing oxygen exposure and microbial contamination.

Storage: Cold rooms, controlled atmosphere (CA) storages, and zero-energy cool chambers help maintain freshness, especially for perishables. Solar-powered cold rooms are now emerging as a sustainable alternative in rural areas.

Transportation: Refrigerated vans and IoT-based

supply chain tracking systems monitor temperature and humidity, alerting users to any deviations during transit.

Benefits of Post-Harvest Mechanization

Reduced Physical Damage: Gentle and uniform handling prevents bruising and cuts.

Increased Shelf Life: Controlled environments slow down spoilage.

Improved Product Quality: Clean, sorted, and properly packaged goods fetch better prices.

Time and Labor Efficiency: Mechanization speeds up operations, especially during peak harvest.

Economic Gains: Better prices, lower losses, and value addition translate into higher incomes for farmers.

Technological Innovations in Post-Harvest Mechanization

The agriculture sector is witnessing rapid technological transformations:

Smart Sensors: Detect ripeness, moisture, and gas levels to optimize harvest timing and storage conditions.

Artificial Intelligence: Enables smart grading, predictive shelf life estimation, and logistics optimization.

Mobile Apps: Help farmers monitor storage units and get market alerts.

Blockchain: Improves traceability and transparency in the supply chain.

Solar-powered Cold Chains: Offer sustainable solutions for off-grid rural locations.

Challenges and Limitations

Despite its advantages, mechanization faces several hurdles:

High Capital Costs: Machines and storage units are expensive for small farmers.

Lack of Training: Farmers need support to operate and maintain equipment.

Poor Infrastructure: Rural roads, electricity, and internet access are still inadequate in many areas.

Limited Awareness: Many farmers still use traditional post-harvest methods due to lack of exposure to modern tools.

Fragmented Land Holdings: Make individual investments in mechanization unviable.

Policy and Institutional Support

Governments and institutions play a key role in promoting mechanization:

- ✓ PMKSY (Pradhan Mantri Kisan Sampada Yojana) supports agro-processing and cold chains.
- ✓ MIDH (Mission for Integrated Development of Horticulture) provides infrastructure grants.
- ✓ Custom Hiring Centers allow shared access to machinery.
- ✓ NABARD and SFAC provide financial assistance and training.
- ✓ Public-Private Partnerships (PPP) enable cost-effective innovation deployment.

International organizations like FAO, UNDP, and IFPRI also provide funding, research, and capacity-building support.

Conclusion

Post-harvest mechanization is not just about

machines it's about transforming agriculture into a more productive, efficient, and profitable sector. Reducing food losses and increasing shelf life can lift millions out of poverty, make farming sustainable, and feed more people with less waste. But this requires collaboration between governments, innovators, farmers, and consumers. With supportive policies, financial inclusion, and widespread adoption of smart technologies, the dream of zero post-harvest waste is not far-fetched. Mechanization is the bridge between hard-earned farm produce and a healthier, hunger-free world.

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From Soil to Sky: Exploring the Spiritual Science behind Bio-Dynamic Farming

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Abstract

The paper explores the transition from harmful chemical-based agriculture to sustainable practices, with a special focus on biodynamic farming. Biodynamic farming is introduced as an enhanced, spiritually-attuned form of organic agriculture. This approach treats the farm as a living organism, aligning agricultural activities with lunar cycles and cosmic rhythms. A case study of Mr. Navaneethakrishnan, a Tamil Nadu farmer, illustrates real-world success. His biodynamic practices have led to healthier crops and measurable increases in beneficial compounds, validated by laboratory tests. This way of farming could address environmental, health, and food security challenges while honoring ancient ecological knowledge.

Introduction

Right from the introduction of the Green Revolution, Commercial agriculture has been satiating the hunger of more than 143 million of Indian population. But, “Are we aware of the negative consequences endured with commercial agriculture?” A shocking report says that, “Even mother's milk has residues of DDT in the range of 3.2 micrograms per gram of fat”. Another recent study of Natural Sustainability 2022 reveals that, “Fertilizer pollution contributes about 1 in 7 deaths, especially near farming regions”. To overcome these vulnerable effects, Indian farmers are showing interest in practicing environmentally friendly methods like Organic farming, Natural farming, etc. But, “Have you heard about an existing enhanced

form of organic farming?” Let us explore this ancient yet a new approach of farming in this upcoming article.

Corrupting Chemical Farming - A Silent Threat to Soil, Humans, Microbes and the Earth:

In the race to boost agricultural productivity, the world turned towards chemical-based conventional farming. At first, it seemed like a revolution. Chemical fertilizers, pesticides and herbicides promised higher yields and better profits. But behind this green illusion lies a darker truth: chemical farming is corrupting the very essence of life - our soil, health, biodiversity, and the planet. Healthy soil is a living ecosystem teeming with microbes, earthworms and fungi. Chemical fertilizers, especially nitrogen, phosphorus and potassium (NPK), disrupt

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this balance. As a result, the soil loses its fertility and becomes dependent on synthetic input, just like a drug addict.

Retrogressing towards forefathers' farming practice: Realizing the dreadful situation which chemical farming has caused, the only solution is retrogressing towards our forefathers' farming practices. Some of the key aspects of our forefathers' farming practices include diversified cropping system to reap year-round income, recycling of on-farm resources, mulching and cover cropping to conserve soil & moisture, integration of native breeds of livestock to obtain valuable inputs for organic preparations like cow urine and cow dung, avoidance of external inputs which potentially deteriorate our native soil, crop rotation, agro forestry and saving local seeds to promote genetic diversity.

A Journey to Blissful Biodynamic farming: Back in the 1920s, farmers were really worried that their soil's fertility level was decreasing, crops weren't growing like they used to and animals were getting weaker. So, Rudolf Steiner, an Austrian philosopher, who was into science and spirituality, helped farmers by giving lectures in 1924, which kicked off what we now call biodynamic farming. He basically said, "Look, a farm isn't just a piece of land - it's like a living organism. You got to take care of it as a whole, not



just pump chemicals into it. He told them to use natural stuff like compost made with special herbs, plant by the moon cycles, and even consider the energy of the earth and cosmos". It may sound a little weird, but the idea was to bring balance back to farming, healthy soil, strong plants, and happy animals. That's how biodynamic farming started, trying to fix the damage and go back to working with nature instead of against it.

Harmonious rhythm with the Earth and the Cosmos: Do you wonder why the biodynamic farming approach is often regarded by the term "Agricultural astrology"? It's named in such a way because biodynamic farming has a profound connection to spirituality. It's an intertwined nature of the physical and metaphysical realms. The approach of biodynamic farming interconnects every element in the farm, right from soil to plants, animals, human beings and even weeds. Biodynamic farming plays a vital role in promoting a plant's overall health and growth wherein symbiotic relationship exists among different components of the farm. Biodynamic farming focuses on long term pest control and deterrence rather than short and quick fixing chemical pest control. Firstly, this approach focuses on augmentation of soil health, wherein microbes act as a frontline of defense for combating harmful pests. Secondly, biodiversity within farm is maintained by cultivating wide variety of plant species which enhance presence of ample beneficial microbes that can act as natural predators for pests.

Thirdly, companion planting, an another component of biodynamic farming, in which deficiency of one plant is compensated by the positive influence of the neighboring plant. One of the significant strategies practised in biodynamic farming is vortex stirring, wherein a rhythmic stirring motion is given to blend biodynamic preparations. The reason behind this vortex stirring is to enrich the preparations with life force and enhance their potency.

Lunar cycles are used to determine significant farming activities like planting and harvesting. The distance between moon and earth increases and is called ascending days. It lasts for 13.6 days. At this phase, the earth breathes out and growth above ground is considered significant. In these ascending days, we can perform operations like:

- ✓ Sowing seeds in direct seed sowing methods and raising seedlings
- ✓ Spraying liquid manures and Panchagavya as foliar sprays
- ✓ Spraying BD 501 (horn silica)
- ✓ Harvesting leafy vegetables and fruits

The distance between earth and moon decreases which is called descending days. During these days, the earth breathes in. Growth below ground is prominent. In these descending days, following agricultural operations are carried out:

- ✓ Transplanting of seedlings
- ✓ Compost making and compost application to the field
- ✓ Ploughing

- ✓ BD 500 (Horn manure), CPP and liquid manure application to the soil
- ✓ Harvesting bulbs and tuber crops

Under the impression of biodynamic farming, “Plants are not viewed as individual biological entities. Instead, plants are revered as human beings possessing spiritual qualities that can interact, influence and balance one another. Just as every human being emits an unique energy signature, so too does each plant.”

Unveiling Success Story of an Indian Farmer: As students pursuing Agriculture, we were supposed to undergo the RAWE Programme which is Rural Agricultural Work Experience, as



a part of our curriculum. We were allotted with a separate block of Karamadai, located in Coimbatore. During this 65 days of program, we were exposed to multiple learning opportunities like interaction with farmers, FPO, ADA and Agro-Industry. One among the profound learning experiences we gained is the visit to Mr. Navaneethakrishnan's farm, who is practising biodynamic farming in his village Chikkadasam-palayam. His farm owns certification of PGS India - Green (Participatory Guarantee System) and PGS India - Organic. Mr. Navaneethakrishnan has published a book on Biodynamic farming titled “Uyiraatral Velaanmai“, in Tamil. Within a limited acreage of area, he is practising multi-cropping system by cultivating a variety of plants like Sweet lime, Guava, Papaya and Yam

provided with appropriate spacing. We noticed fig trees in his farm, which reaped him additional income. While interacting with the farmer, we came to know that they're nurturing every component in their farm just like pampering a new born baby.

He says, "In our farm, we make boundless efforts to make each component like soil, plants, microbes and animals, blissful. The happier they are, better the quality of fruits they produce. In turn, healthier and happier human beings who intake our farm grown fruits. In our farm, we make sure that even weeds are not harmed. In case they cause menace, we cover the weeds with mulch cover, rather than spraying toxic herbicides. We truly believe in the influence of earthly forces like plants, microbes with outer space forces like the moon, the stars and the constellations. We schedule our significant agricultural activities like planting, spraying and harvesting according to lunar phases. As a result, sweet lime grown in our farm is enriched with more amounts of hesperidin and polyphenol content than the usual one, which is also proven by Ammagenomics laboratory, a NABL accredited food testing lab in Chennai. Normal content of total polyphenol is about 440 mg kg⁻¹ and the fruits grown in our field contain about 980 mg kg⁻¹, whereas normal content of hesperidin is about 74 mg kg⁻¹ and the fruits reaped from our farm contain about 316 mg kg⁻¹. In fact, Curcumin content in our farm grown turmeric is about 64.51%, whereas normally it consists only about 31.61 %. We do make our own organic preparations like CPP, BD 500, BD 501,

Liquid manures and Panchagavya, which act as a powerful deterrent of pests, diseases as well as growth enhancers. CPP commonly called Cow Pat Pit is produced from organic inputs like cow dung, cow urine, egg shell powder and it is enriched with hydrocarbon degrading bacteria. BD 500 which is Horn manure and can be used to degrade residual effect of herbicides. BD 501 which is Horn silica manure, and it enhances keeping quality of crops, due to the presence of silica".

Indeed, it was very hard for us to believe in a farming method which is based on the lunar calendar, but later, looking at the lab results with our own eyes, we came to the conclusion that science behind biodynamic farming is true and really fascinating.

Conclusion

This world is moving steadfast towards technology-driven agriculture. But indeed we are forgetting our ancient traditional farming. What if we integrate traditional agriculture with technology? So just give it a thought. To conclude, it's more appropriate to end with a quote from Rudolf Steiner, "For every human illness, somewhere in the world there exists a plant which is the cure. I believe that there is a healing potential locked inside plants which is integral with their evolution, just as it is part of human evolution to learn to tap this wonderful gift of Nature".

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Cultivating Health: Science in Action-India's Expanding Blueprint for Global Food Safety

Dinesh Chandra Rai

As the global food community observes World Food Safety Day 2025 on 7th June, under the critical theme “Food Safety: Science in Action,” it is imperative to recognize that the integrity of our food systems directly underpins the health, economic stability, and social well-being of nations worldwide. Food safety is not merely a localized concern; it is a complex scientific endeavor and a shared international responsibility. Academic institutions are deeply committed to advancing the scientific understanding of food safety, innovative solutions, and cultivating the next generation of experts who will champion these crucial efforts. The journey of food, from the agricultural fields to the consumer's plate, is inherently susceptible to various hazards microbial pathogens, chemical contaminants, physical foreign bodies, and deliberate adulteration. Navigating these risks demands rigorous scientific inquiry to identify emerging threats, develop precise detection methodologies, engineer effective preservation techniques, and construct robust regulatory frameworks. This is precisely where “Science in Action” translates from theory into tangible progress. India's Dynamic Contribution to Global Food Safety India, with its vast agricultural output, diverse culinary heritage, and an enormous populace exceeding 1.4 billion, undeniably occupies a central

position in the global food safety dialogue. Our nation's remarkable trajectory from self-sufficiency to becoming a significant food exporter is a testament to the dedication of our agricultural sector and scientific community. This scale, however, necessitates equally scaled and sophisticated approaches to ensure food safety.

Historically, India's traditional food practices often incorporated intuitive principles of food safety, such as the use of spices with natural antimicrobial properties, fermentation for preservation, and sun-drying techniques. These ancient wisdoms, now increasingly validated by modern scientific research, provide a foundational understanding that informs contemporary food safety strategies. In 2024, India continued its proactive trajectory in formalizing and bolstering its national food safety infrastructure. The Food Safety and Standards Authority of India (FSSAI), operating under the Ministry of Health and Family Welfare, has been a driving force. A key highlight was the release of the State Food Safety Index (SFSI) 2024. This innovative benchmarking tool meticulously evaluates states and union territories across critical parameters including Human Resources and Institutional Data, Compliance, Food Testing-Infrastructure and Surveillance, Training and Capacity Building and Consumer Empowerme-

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nt. Notably, Kerala secured the top position among large states for the second consecutive year, a clear indicator of robust efforts in inspections, sample collection, laboratory testing, and public awareness campaigns. This index serves as a powerful mechanism for healthy competition and catalyzing positive change within the federal structure, ultimately enhancing food safety outcomes nationwide.

While the SFSI highlights overall performance and progress, a closer look at compliance data reveals the ongoing challenges and areas requiring intensified efforts. As per various reports from 2024, a significant portion of food samples tested across India were found to be non-compliant with safety standards. For instance, data from Punjab indicated that in the financial year 2023-24, approximately 15.4% of food samples failed quality checks. This figure, while fluctuating, highlights the persistent threat of non-compliant or adulterated food products. It underscores the critical need for continuous vigilance, robust enforcement and improved adherence to regulations by Food Business Operators (FBOs). This proactive approach, combining regulatory oversight with public empowerment and targeted enforcement, is crucial for improving these statistics.

Furthermore, FSSAI's "Eat Right India" movement continued its robust expansion in 2024. Beyond regulatory enforcement, this initiative actively cultivates consumer awareness and promotes a widespread culture of safe and healthy food choices. India's active participation in significant

global events, such as hosting the Global Food Regulators Summit (GFRS) 2024, underscores its commitment to international collaboration and knowledge exchange.

Pioneering Food Safety Innovation from India

"Science in Action" is inherently driven by continuous innovation. Indian research institutions and scientists are increasingly at the forefront of cutting-edge developments in food safety:

Addressing Emerging Contaminants: A pivotal initiative in 2024 was FSSAI's launch of a dedicated project to tackle microplastic contamination in Indian food. This forward-thinking project aims to develop validated methodologies for detecting micro- and nano-plastics and meticulously assess their prevalence across diverse food matrices. This proactive measure demonstrates India's foresight in confronting evolving global food safety threats and its dedication to science-driven interventions. The National Green Tribunal (NGT) also played a role in 2024, emphasizing the need to address microplastic infiltration.

Advanced Analytical Capabilities: Scientific panels within FSSAI consistently review and endorse advancements in Rapid Analytical Food Testing (RAFT) technologies. The focus remains on developing faster, more accurate, and economically viable tools for pathogen identification, chemical residue detection, and adulterant screening. The consistent improvements in state-level food testing infrastructure, as highlighted by the SFSI 2024, are a direct outcome of this scientific emphasis.

Leveraging Digital Transformation: The integration of Artificial Intelligence (AI) and data analytics is transforming food safety surveillance. While still evolving, 2024 saw continued efforts to utilize these technologies for predictive modeling of foodborne illness outbreaks, anomaly detection in supply chains, and enhanced traceability, making India's food systems more resilient.

Sustainable Packaging Solutions: Research and policy discussions in 2024, including FSSAI's launch of rPET guidelines, indicate a growing emphasis on sustainable packaging materials and novel preservation techniques that extend shelf life while maintaining nutritional integrity and safety, crucial for reducing food waste in a climate-challenged world.

India's Strategic Role in Global Food Safety Governance

India's dedication to food safety extends significantly beyond its national borders. As a major contributor to global food production and a key trading partner, India recognizes that food safety is a collective responsibility, demanding robust international cooperation. India demonstrated its heightened engagement in global forums, particularly within the Codex Alimentarius Commission (CAC). India's recent election to the Executive Committee of the CAC signifies its increasing influence in shaping harmonized international food standards. Our active participation in various Codex meetings, including the hosting of the 7th Session of the Codex Committee on Spices and Culinary Herbs

in Kochi, solidified India's leadership in advocating for science-based standards that are globally applicable yet sensitive to regional contexts. India's proposals, particularly for a global standard for millets, showcased our commitment to promoting safe and nutritious traditional foods on the international stage.

The successful organization of the Global Food Regulators Summit (GFRS) 2024 in India was a landmark event. This summit brought together food regulators and experts from over 70 countries, facilitating critical dialogues on global food safety standards, risk assessment, antimicrobial resistance, and leveraging technology for better food regulation. It served as a powerful platform for sharing best practices and fostering collaborative pathways to strengthen global food safety systems, effectively positioning India as a thought leader in this crucial domain.

The Path Forward: Sustaining Scientific Vigilance and Collaboration

While India has made commendable progress, challenges persist, especially in the informal food sector and ensuring uniform adherence to safety protocols across its vast and intricate supply chain. The ongoing need for FSSAI to issue advisories and step up checks on issues like plastic use in idli preparation or dairy analogues, even in 2024, underscores the continuous need for vigilance. The non-compliance rates highlight that much work remains to be done. Addressing these requires:

Amplified Research and Development: Continued

investment in cutting-edge food science and technology research, fostering dynamic interdisciplinary collaborations between academia, industry, and government. The focus on emerging threats, as exemplified by the microplastics project, must remain a priority.

Comprehensive Capacity Building: Expanding robust training programs for food handlers, regulatory personnel, and consumers to embed a deep understanding of food safety principles. Our universities must play a pivotal role in producing highly skilled food safety professionals equipped to address both current and future challenges.

Robust Enforcement and Surveillance: Strengthening inspection mechanisms and leveraging technology for enhanced traceability systems, ensuring transparency and accountability at every stage of the food chain. The SFSI 2024 results demonstrate that consistent inspection and surveillance drive positive outcomes, and these efforts must be intensified to reduce the percentage of non-compliant food.

Strengthened International Partnerships: Deepening collaborations with global bodies like FAO and WHO, and with individual nations, to share insights, harmonize regulations, and effectively address transboundary food safety issues. India's role in global forums is crucial for harmonizing standards and responding to global food safety incidents effectively.

As Vice Chancellor, I am immensely proud of our nation's progress and the invaluable contribu-

tions our academic and scientific communities are making to this vital field. "Cultivating Health: Science in Action" is more than a theme; it is our guiding principle. By relentlessly pursuing scientific innovation, fortifying our regulatory frameworks, and nurturing a pervasive culture of food safety awareness, India is not only safeguarding the health of its own populace but also playing an increasingly indispensable role in ensuring safe, nutritious, and sustainable food for the entire world. Let us collectively continue to harness the power of science to secure our food and cultivate a healthier future for all.

About the Author

Prof. Dinesh Chandra Rai is Vice Chancellor of BRA Bihar University, Muzaffarpur Bihar and a leading expert in Dairy Science and Food Technology. With around 30 years of experience in academics and research with prestigious BHU, Varanasi, he has authored numerous publications on food processing and safety, focusing on sustainable practices. Prof. Rai's initiatives have trained thousands of farmers and professionals, strengthening India's food safety ecosystem. His contributions to FSSAI's scientific panels and international collaborations have advanced standards for millets and dairy, earning him global recognition.

Vegetable Grafting: A New Approach to Increase Farmer's Profit

Shobharam Thakur, Nisha Chadar and Dwarka

Abstract

Vegetable grafting is an innovative agricultural technique that enhances crop resilience, improves yield, and increases farmers' profitability. By combining the rootstock of disease-resistant varieties with high-yielding scions, grafting offers a sustainable solution to common challenges such as soil-borne diseases, drought stress, and poor soil conditions. This approach not only reduces the need for chemical pesticides but also extends the growing season and improves overall crop quality. As global demand for sustainable and high-yield agricultural practices rises, vegetable grafting presents a viable method for small- and large-scale farmers to maximize returns while promoting environmental sustainability. This paper explores the principles of vegetable grafting, its economic benefits, and its potential to revolutionize modern farming practices.

Introduction

Vegetable grafting is an innovative agricultural technique that enhances crop yield, improves disease resistance, and boosts overall profitability for farmers. This method involves joining the rootstock of a disease-resistant plant with the scion of a high-yielding variety, resulting in a hybrid plant with superior characteristics. Originally developed for fruit trees, grafting has gained popularity in vegetable production, particularly for crops like tomatoes, eggplants, cucumbers, and peppers.

Benefits of Vegetable Grafting

Increased Disease Resistance: Grafting helps combat soil-borne diseases, such as bacterial wilt, fusarium wilt, and nematodes, which are common

threats to vegetable crops. The use of resistant rootstocks reduces the need for chemical pesticides, making farming more sustainable and eco-friendly.

Improved Yield and Quality: By combining the strengths of different plant varieties, grafted vegetables exhibit enhanced growth, higher yields, and better fruit quality. Farmers can achieve increased production with fewer losses due to disease and environmental stress.

Enhanced Tolerance to Environmental Stress: Grafted plants show greater resilience to drought, salinity, and extreme temperatures. The robust root system of the rootstock provides efficient nutrient and water uptake, ensuring consistent growth even under challenging conditions.

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Reduced Dependency on Chemical Inputs: Since grafted plants have natural resistance to pests and diseases, farmers can reduce their reliance on synthetic fertilizers and pesticides. This lowers production costs and promotes eco-friendly farming practices.

Extended Growing Seasons: Grafting allows for early planting and extended harvest periods, enabling farmers to supply markets for longer durations and secure better prices for their produce.

Challenges in Vegetable Grafting

Despite its advantages, vegetable grafting also presents some challenges:

High Initial Cost: The process requires investment in specialized grafting tools, labor, and nursery facilities.

Technical Expertise: Successful grafting demands skill and knowledge to ensure high grafting success rates.

Limited Availability of Grafted Seedlings: In some regions, obtaining quality grafted seedlings can be difficult due to inadequate supply chains.

Implementation Strategies

Training and Education: Providing farmers with training programs and workshops on grafting techniques can improve adoption rates and success in implementation.

Government and Institutional Support: Agricultural policies should support research, subsidies, and extension services to encourage farmers to adopt grafting practices.

Collaboration with Research Institutions: Partner-

ships between farmers, universities, and agricultural organizations can facilitate the development of improved grafting techniques and the availability of high-quality grafted seedlings.

Conclusion

Vegetable grafting presents a promising solution for farmers seeking to increase productivity and profitability while minimizing environmental impact. By addressing challenges such as disease management, climate stress, and input costs, this technique offers a sustainable pathway for modern vegetable production. With continued research, investment, and farmer education, vegetable grafting can revolutionize farming practices and contribute to global food security.

Impact of Climate Change on Indian Agriculture and Its Mitigation

Shobharam Thakur, Nisha Chadar and Dwarka

Abstract

Climate change has emerged as a significant challenge for Indian agriculture, impacting crop yields, water availability, and soil health. Rising temperatures, erratic rainfall patterns, and extreme weather events threaten food security and farmer livelihoods. This paper discusses the major effects of climate change on Indian agriculture and explores mitigation strategies such as climate-resilient crops, water conservation, soil health management, agroforestry, precision farming, and policy interventions. Implementing these measures can enhance resilience, improve productivity, and ensure sustainable agricultural growth in the face of climate variability.

Introduction

India, a predominantly agrarian economy, heavily relies on agriculture for food security, employment, and economic growth. However, climate change poses a severe threat to the sector, affecting crop yields, water availability, and soil health. Rising temperatures, erratic rainfall patterns, and extreme weather events have significantly altered agricultural productivity. Addressing these challenges requires a multi-pronged approach involving adaptive strategies, technological innovations, and policy interventions.

Impacts of Climate Change on Indian Agriculture

Rising Temperatures: Increasing temperatures lead to heat stress in crops, reducing yields, particularly for wheat, rice, and maize. Higher temperatures accelerate evaporation, leading to moisture loss and

soil degradation.

Erratic Rainfall and Droughts: Unpredictable monsoon patterns disrupt the cropping calendar, affecting sowing and harvesting seasons. Prolonged dry spells lead to droughts, causing water scarcity and lower agricultural output.

Floods and Extreme Weather Events: Intense rainfall and cyclones result in flooding, soil erosion, and crop destruction, particularly in coastal and low-lying agricultural regions.

Declining Soil Fertility: Changes in precipitation patterns and temperature variations impact soil organic matter, leading to nutrient depletion and reduced soil fertility.

Pest and Disease Outbreaks: Warmer temperatures create favorable conditions for pests and diseases, threatening crop health and increasing dependency

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on chemical pesticides.

Mitigation Strategies for Climate-Resilient Agriculture

Adoption of Climate-Resilient Crops: Developing and promoting drought-tolerant, heat-resistant, and flood-resistant crop varieties can help maintain productivity under changing climatic conditions.

Water Conservation Techniques: Efficient irrigation systems such as drip and sprinkler irrigation, rainwater harvesting, and watershed management can reduce water stress and enhance water use efficiency.

Soil Health Management: Practices like crop rotation, organic farming, mulching, and integrated nutrient management help restore soil fertility and prevent degradation.

Agroforestry and Diversification: Integrating trees, shrubs, and multiple crops in farmlands enhances resilience, reduces greenhouse gas emissions, and provides alternative income sources for farmers.

Precision Farming and Technology Integration:

The use of remote sensing, AI-based weather forecasting, and sensor-based soil analysis helps optimize resource use and mitigate climate-related risks.

Policy and Government Initiatives: Government schemes such as the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) for irrigation, the National Adaptation Fund for Climate Change (NAFCC), and crop insurance programs like PMFBY (Pradhan Mantri Fasal Bima Yojana) support farm-

ers in managing climate risks.

Awareness and Capacity Building: Educating farmers about climate-smart agricultural practices and sustainable farming techniques through extension programs and digital platforms empowers them to adapt effectively.

Conclusion

Climate change poses a formidable challenge to Indian agriculture, necessitating immediate and sustained mitigation efforts. Through a combination of resilient crop varieties, efficient resource management, technological advancements, and supportive policies, the agricultural sector can withstand climate shocks while ensuring food security and sustainable livelihoods for millions of farmers. Collective action from government bodies, research institutions, and farmers will be crucial in building a climate-resilient agricultural system in India.

Plant Protection in Summer Maize Crop

Shobharam Thakur, Nisha Chadar and Dwarka

Abstract

Maize is a vital cereal crop that faces several challenges during the summer season, including pest infestations, diseases, weed competition, and heat stress. Effective plant protection strategies are essential to ensure optimal crop growth and yield. This paper discusses integrated pest and disease management approaches, including the use of chemical and biological control methods against major threats such as fall armyworm, stem borer, and leaf blight. Weed management through herbicides and cultural practices is also emphasized. Additionally, strategies for mitigating heat stress, such as proper irrigation scheduling, mulching, and the use of anti-transpirants, are highlighted. By implementing these practices, maize farmers can minimize crop losses and enhance productivity during the summer season.

Introduction

Maize (*Zea mays*) is one of the most important cereal crops cultivated worldwide, serving as a staple food and a key raw material for various industries. However, maize production in the summer season faces several challenges due to high temperatures, erratic rainfall, pest infestations, and disease outbreaks. These factors can significantly reduce crop yield and quality if not managed effectively. Plant protection plays a crucial role in safeguarding the maize crop against biotic and abiotic stresses. Pests such as fall armyworm (*Spodoptera frugiperda*) and stem borers (*Chilo partellus*) can cause severe damage, while diseases like turicum leaf blight, downy mildew, and rust can

spread rapidly under favorable conditions. Additionally, weeds compete with maize plants for nutrients, water, and sunlight, further affecting growth. To ensure a healthy maize crop during the summer season, an integrated approach combining cultural, biological, and chemical control measures is essential. This paper discusses various strategies for managing pests, diseases, and weeds, as well as methods to mitigate heat stress, ensuring sustainable maize production and higher yields. Below are key measures to safeguard maize crops in summer:

Pest Management

Common Pests in Summer

Fall Armyworm (*Spodoptera frugiperda*)

Symptoms: Irregular holes in leaves, damage to

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whorls.

Control: Spray Spinosad 45 SC (0.3 ml liter⁻¹ of water) or Emamectin benzoate 5 SG (0.4 g liter⁻¹ of water). Apply neem-based biopesticides (Azadirachtin 1%). Install pheromone traps (5-6 per acre).

Stem Borer (*Chilo partellus*)

Symptoms: Holes in stems, dead heart symptoms in young plants.

Control: Release *Trichogramma chilonis* parasitoids.

Aphids, Jassids and Whiteflies

Symptoms: Leaf curling, yellowing, stunted growth.

Control: Spray Imidacloprid 17.8 SL (0.3 ml liter⁻¹ of water) or Thiamethoxam 25 WG (0.2 g liter⁻¹ of water). Encourage natural predators (lady beetles, lacewings).

Disease Management

Common Diseases in Summer

Turcicum Leaf Blight (*Exserohilum turcicum*)

Symptoms: Large elongated brown lesions on leaves.

Control: Spray Mancozeb 75 WP (2.5 g liter⁻¹ of water) or Propiconazole 25 EC (1 ml liter⁻¹ of water). Use resistant varieties.

Downy Mildew (*Peronosclerospora sorghi*)

Symptoms: Yellow streaks on leaves, white fungal growth under leaves.

Control: Use Metalaxyl 35 WS (6 g kg⁻¹ of seed) for seed treatment. Spray Metalaxyl + Mancozeb (2.5 g liter⁻¹ of water).

Rust (*Puccinia sorghi*)

Symptoms: Reddish-brown pustules on leaves.

Control: Spray Propiconazole 25 EC (1 ml liter⁻¹ of water). Grow resistant hybrids.

Weed Management

Pre-emergence herbicides: Atrazine 50 WP (1 kg acre⁻¹) within 2-3 days after sowing.

Post-emergence herbicides: Tembotrione 42 SC (120 ml acre⁻¹) after 20-25 days of sowing.

Manual weeding: First weeding at 20-25 days and second at 40-45 days after sowing.

Irrigation and Heat Stress Management

Regular Irrigation

Critical stages: Germination, knee-high stage, flowering, and grain filling. Avoid water stress during flowering and grain filling.

Mulching: Use crop residues, straw, or plastic mulch to retain moisture.

Anti-Transpirants: Spray Kaolin (5%) or Silicon-based sprays to reduce heat stress.

Nutrient Management for Healthy Growth

Apply balanced fertilizers

Nitrogen (Urea): 50% at sowing, 25% at knee-high stage, and 25% at tasseling.

Phosphorus (DAP): At sowing.

Potassium (MOP): At sowing for drought resistance.

Micronutrient spray

- ✓ Zinc Sulphate (0.5%) for healthy growth.
- ✓ Boron (0.2%) to prevent tassel and cob abnormalities.

Conclusion

By implementing integrated pest management (IPM), timely disease control, effective weed

management, proper irrigation, and balanced nutrition, maize crops can be protected from summer stress, ensuring a healthy yield.



Plant Protection in Summer Okra Crop

Shobharam Thakur, Nisha Chadar and Dwarka

Abstract

Okra (*Abelmoschus esculentus*) is a widely cultivated vegetable crop that thrives in warm climates but faces several challenges during the summer season. High temperatures, pest infestations, diseases, and weed competition can significantly reduce yield and fruit quality. This paper explores effective plant protection strategies for okra during the summer, focusing on integrated pest management (IPM), disease control, weed management, and heat stress mitigation. Major pests such as fruit borers, aphids, whiteflies, and red spider mites are discussed, along with control measures using biological and chemical interventions. Common diseases like yellow vein mosaic virus (YVMV), powdery mildew, and damping-off are addressed through resistant varieties, fungicides, and cultural practices. Additionally, weed control through herbicides and manual methods, as well as irrigation and mulching techniques to reduce heat stress, are highlighted. Implementing these protective measures ensures higher productivity, improved fruit quality, and sustainable okra cultivation during the summer season.

Introduction

Okra (*Abelmoschus esculentus*), commonly known as lady's finger, is a popular vegetable crop grown in tropical and subtropical regions. It thrives in warm temperatures but is highly susceptible to pest infestations, diseases, and heat stress during the summer season. These factors can significantly reduce yield and quality, making effective plant protection measures essential. Pests such as fruit borers, aphids, whiteflies, and jassids pose a major threat to okra production, while diseases like powdery mildew, yellow vein mosaic virus (YVMV), and damping-off can further damage the

crop. Additionally, weed competition and extreme heat conditions can affect plant growth. This article discusses integrated pest and disease management approaches, weed control strategies, and methods to mitigate heat stress, ensuring healthy okra production during the summer season.

Pest Management

Fruit and Shoot Borer (*Earias vittella*)

Symptoms: Boreholes in young shoots and fruits, leading to wilting.

Control: Spray Emamectin benzoate 5 SG (0.4 g liter⁻¹ of water) or Spinosad 45 SC (0.3 ml liter⁻¹ of water). Remove and destroy affected shoots and

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fruits.

Aphids, Whiteflies, and Jassids

Symptoms: Leaf curling, stunted growth, yellowing, and honeydew secretion.

Control: Spray Imidacloprid 17.8 SL (0.3 ml liter⁻¹ of water) or Thiamethoxam 25 WG (0.2 g liter⁻¹ of water). Encourage natural predators like lady beetles and lacewings.

Red Spider Mite

Symptoms: Yellowing of leaves with webbing on the underside.

Control: Spray Abamectin 1.9 EC (1 ml liter⁻¹ of water). Avoid water stress to reduce mite infestation.

Disease Management

Yellow Vein Mosaic Virus (YVMV)

Symptoms: Yellowing of veins, stunted growth, reduced fruit production.

Control: Use virus-resistant varieties. Spray Imidacloprid 17.8 SL (0.3 ml liter⁻¹ of water) to control whiteflies (vectors).

Powdery Mildew (*Erysiphe cichoracearum*)

Symptoms: White powdery growth on leaves, reduced photosynthesis.

Control: Spray Sulfur 80 WP (2 g liter⁻¹ of water) or Hexaconazole 5 EC (1 ml liter⁻¹ of water).

Damping-Off (*Pythium* spp., *Rhizoctonia* spp.)

Symptoms: Seedling rot, poor germination.

Control: Treat seeds with profenophos (2 ml l⁻¹ of seed) before sowing. Avoid overwatering and maintain proper drainage.

Weed Management

Pre-emergence herbicides: Apply Pendimethalin

30 EC (1 liter acre⁻¹) after sowing to control weeds.

Post-emergence herbicides: Spray Imazethapyr 10 SL (750 ml acre⁻¹) at 20-25 days after sowing.

Manual weeding: Perform first weeding 20-25 days after sowing and second at 40-45 days.

Heat Stress Management

Irrigation: Water at critical stages like flowering and fruit setting.

Mulching: Use organic mulches like straw or plastic mulch to retain soil moisture.

Anti-Transpirants: Spray Kaolin (5%) or Silicon-based formulations to reduce heat stress.

Conclusion

A well-planned integrated pest and disease management strategy, combined with proper weed control and irrigation techniques, can protect okra crops from summer stress. Adopting these measures ensures higher yield, better quality fruits, and improved farmer profitability during the summer season.

Plant Protection in Summer Pulses

Shobharam Thakur, Nisha Chadar and Dwarka

Abstract

Pulse crops are highly susceptible to various pests, diseases, and environmental stresses during the summer season, impacting yield and quality. Effective plant protection strategies are crucial to ensure healthy crop growth. Major insect pests such as pod borers, aphids, whiteflies, and thrips can be managed through integrated pest management (IPM) practices, including biological control and selective insecticides. Common diseases like yellow mosaic virus, wilt, and powdery mildew require resistant varieties, cultural practices, and timely fungicidal applications. Weed control through pre-emergence herbicides and manual weeding helps reduce competition and pest incidence. Moisture conservation techniques such as mulching, light irrigation, and drought-tolerant varieties mitigate heat stress. Additionally, balanced nutrient application enhances plant resistance against biotic and abiotic stresses. Adopting these holistic approaches ensures sustainable pulse production even under challenging summer conditions.

Introduction

Pulses, including chickpeas, lentils, pigeon peas, mung beans, and black gram, are essential sources of protein and nutrients. However, the summer season poses significant challenges to pulse production due to high temperatures, moisture stress, and increased pest and disease incidences. Proper plant protection measures are essential to safeguard crops from various biotic and abiotic threats. During summer, pulse crops face major pests such as pod borers, aphids, whiteflies, and thrips, which can cause severe yield losses. Similarly, diseases like yellow mosaic virus, wilt, and powdery mildew spread rapidly under warm conditions.

Weeds also compete for nutrients and moisture, further stressing the crops. Additionally, heat and drought stress can reduce germination, flowering, and pod formation, affecting overall productivity. To overcome these challenges, integrated plant protection strategies must be adopted. This includes pest and disease monitoring, biological and chemical control methods, efficient weed management, moisture conservation practices, and proper nutrient application. Implementing these measures ensures healthy crop growth, minimizes losses, and enhances productivity during the summer season. Here are key strategies for managing pests, diseases, and environmental stress:

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Pest Management

Major Pests in Summer

Pod Borers (*Helicoverpa armigera*): Feed on flowers and pods.

Aphids: Suck sap and spread viral diseases.

Whiteflies: Transmit yellow mosaic virus.

Thrips: Cause leaf curling and stunted growth.

Cutworms and Termites: Damage roots and stems.

Control Measures

- ✓ Use pheromone traps for pod borers.
- ✓ Spray neem-based pesticides (Azadirachtin 0.15%).
- ✓ Release biological control agents (*Trichogramma chilonis* for pod borers).
- ✓ Apply insecticides like Spinosad 45 SC (0.3 ml L⁻¹) for severe infestations.
- ✓ Avoid excessive nitrogen fertilizers that attract pests.

Disease Management

Common Diseases in Summer

- ✓ Yellow Mosaic Virus (YMV) (spread by whiteflies)
- ✓ Wilt and Root Rot (due to excessive soil moisture)
- ✓ Powdery Mildew (caused by fungal spores)

Control Measures

- ✓ Grow resistant varieties (e.g., Pusa Vishal for mung bean).
- ✓ Remove infected plants to prevent spread.
- ✓ Spray fungicides like Carbendazim (1 g L⁻¹) for fungal diseases.
- ✓ Control whiteflies with Imidacloprid 17.8 SL

(0.3 ml L⁻¹).

Weed Management

- ✓ Use pre-emergence herbicides like Pendimethalin (1 L acre⁻¹).
- ✓ Regular weeding to reduce pest and disease incidence.
- ✓ Mulching to conserve soil moisture and suppress weeds.

Moisture and Heat Stress Management

- ✓ Provide light irrigation during extreme heat.
- ✓ Use drought-resistant varieties.
- ✓ Apply organic mulches (straw, dried leaves) to retain soil moisture.
- ✓ Avoid waterlogging to prevent root rot.

Nutrient Management

- ✓ Apply phosphorus and potash for better root and pod development.
- ✓ Foliar spray of micronutrients (Zn, Fe, and Boron) to boost plant immunity.

Conclusion

Effective plant protection during the summer season is crucial for ensuring the healthy growth and productivity of pulse crops. The combination of high temperatures, pest infestations, disease outbreaks, and moisture stress can significantly impact yields. Integrated pest management (IPM), including biological control, resistant varieties, and judicious use of pesticides, plays a vital role in minimizing damage caused by insects and diseases. Proper weed management, moisture conservation techniques, and balanced nutrient application further strengthen plant resilience against summer stress.

By adopting a holistic approach that incorporates cultural, mechanical, biological, and chemical control methods, farmers can protect pulse crops and sustain productivity. Timely interventions and eco-friendly practices will not only enhance yield but also promote sustainable and environmentally friendly agriculture.



Sustainable Orchard Management: A Guide to Eco-Friendly Fruit Production

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Abstract

Sustainable orchard management is a holistic approach that ensures the long-term health of fruit trees while minimizing environmental impact. It integrates eco-friendly practices, soil conservation, biodiversity promotion, and responsible resource use to create a productive and resilient orchard ecosystem.

Introduction

As the demand for organically grown and environmentally responsible food continues to rise, sustainable orchard management has become an essential practice for modern fruit growers. Traditional orchard practices, often reliant on synthetic fertilizers, pesticides, and intensive water usage, can have detrimental effects on soil health, biodiversity and surrounding ecosystems. Sustainable orchard management, on the other hand, focuses on long-term ecological balance, enhancing productivity while reducing negative environmental impacts. This approach integrates practices such as organic soil enrichment, natural pest control, efficient irrigation techniques, agroforestry, and biodiversity conservation to create a thriving orchard ecosystem that not only supports fruit production but also fosters pollinators, beneficial insects, and native

wildlife. Additionally, climate change presents new challenges for fruit growers, making it increasingly necessary to implement strategies that improve resilience to extreme weather events, droughts, and shifting seasonal patterns. Sustainable orcharding promotes soil regeneration through cover cropping, composting, and reduced tillage while encouraging carbon sequestration to mitigate greenhouse gas emissions. Moreover, adopting eco-friendly orchard management is not only beneficial for the environment but also economically viable, as consumers and markets show a growing preference for sustainably produced fruits. This guide provides a comprehensive approach to sustainable fruit production, offering practical techniques and insights for growers who seek to balance profitability with ecological responsibility. By embracing regenerative agriculture, permaculture principles,

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and holistic orchard care, fruit growers can cultivate resilient, productive orchards that contribute to a healthier planet while delivering high-quality, nutritious produce to consumers. Whether you are an experienced orchardist looking to transition to sustainable methods or a new grower seeking to establish an eco-friendly orchard from the start, this guide serves as an invaluable resource for understanding and implementing best practices that support both the land and future generations.

Soil Health and Fertility

Maintaining healthy soil is fundamental to sustainable orcharding. Practices include:

Compost and Organic Matter: Adding compost, manure, and cover crops improves soil structure and fertility.

Crop Rotation and Cover Crops: Planting cover crops such as clover or vetch enhances nitrogen levels and prevents soil erosion.

Minimal Tillage: Reducing soil disturbance preserves beneficial microorganisms and improves water retention.

Water Conservation

Efficient water use is crucial for sustainability. Strategies include:

Drip Irrigation: Reduces water waste and delivers moisture directly to tree roots.

Mulching: Retains soil moisture, suppresses weeds, and moderates soil temperature.

Rainwater Harvesting: Capturing and storing rainwater reduces dependence on external water sources.

Integrated Pest Management (IPM)

IPM reduces chemical pesticide use and enhances natural pest control methods:

Beneficial Insects: Encouraging ladybugs, lacewings, and bees to control pests naturally.

Companion Planting: Growing plants that repel pests or attract beneficial insects.

Biological Controls: Using natural predators and organic solutions like neem oil to manage infestations.

Biodiversity and Pollinator Support

A diverse orchard ecosystem fosters resilience:

Native Plants and Wildflower Strips: Attract pollinators and beneficial insects.

Habitat Conservation: Maintaining hedgerows and nesting sites for birds and bees.

Crop Diversity: Growing multiple fruit varieties enhances resistance to pests and diseases.

Organic and Regenerative Practices

Avoiding synthetic chemicals and enhancing soil regeneration ensures long-term productivity:

Organic Fertilizers and Compost Teas: Feed soil microbes and enhance tree nutrition.

Agroforestry Techniques: Integrating trees and shrubs with crops for a balanced ecosystem.

No Synthetic Pesticides: Reducing chemical inputs to prevent soil and water contamination.

Waste Reduction and Recycling

Minimizing waste contributes to sustainability:

Pruning Waste Utilization: Composting branches

or using them as mulch.

Fruit and Organic Waste Recycling: Converting damaged or excess fruit into compost or animal feed.

Eco-friendly Packaging: Using biodegradable or reusable containers for fruit distribution.

Community and Economic Sustainability

Engaging with local communities supports long-term orchard success:

Local Markets and CSA Programs: Selling produce locally reduces transportation emissions and supports regional economies.

Educational Initiatives: Hosting workshops on sustainable farming practices.

Fair Labor Practices: Ensuring ethical treatment and fair wages for workers.

Conclusion

Sustainable orchard management is an ongoing commitment that benefits both the environment and the grower. By implementing eco-friendly strategies, orchardists can maintain soil fertility, support biodiversity, conserve water and reduce waste while producing high-quality fruit. A sustainable approach not only ensures long-term productivity but also fosters a thriving ecosystem for future generations.

Strawberry Runner Production: A Sustainable Economic Solution to Empower Women in Rural Areas of Himachal Pradesh

Anshul Kumar, Dharam Paul Sharma and Pankaj Kumar

Abstract

The strawberry (*Fragaria × ananassa* Duch.) is among world's most popular and appealing fruit known for its delicious and refreshing quality and health benefits. It is rich in minerals, vitamins and also offers cardiovascular benefit. Strawberries are commercially propagated through runners. The climate of the lower hills of Himachal Pradesh is excellent for producing high-quality fruits, while the climate of the medium and high ranges is ideal for producing top-quality runners. Strawberry is a widely commercialized fruit that has the ability to provide economic benefits to growers. It is easy to cultivate, and women in rural Himachal Pradesh can easily undertake strawberry cultivation and runner production, resulting in Socio-economic advancement and sustainable livelihoods of rural women via the strawberry runner production and the development of employment possibilities in the community.

Introduction

The strawberry (*Fragaria × ananassa* Duch.) is among world's most popular and appealing fruit known for its delicious and refreshing quality and health benefits (Yang *et al.*, 2024; Bai *et al.*, 2023). It is a member of family Rosaceae and all the cultivated varieties are octaploid in nature having chromosome number $2n = 56$ (Anchal *et al.*, 2023). Botanically it is an aggregate fruit which is highly perishable, non-climatic and small in size with an edible portion (fleshy thalamus) of 98%. Strawberry is a short day herbaceous crop, behaves as perennial in temperate condition and as annual in sub-tropical climate (Bai *et al.*, 2023).

It has a shallow root system and is grown both in open fields and under protection in greenhouses. As an herbaceous annual fruit crop, it is easily grown in kitchen gardening, on roof-tops pots and containers as well. Strawberry is considered as a functional food with antioxidant and antihypertensive properties as they are rich in, minerals like K, Mg, and Ca, vitamins, organic acids, and anti-carcinogens and also offer cardiovascular benefit. However, low calorie and carbohydrate content in fruit provides numerous health benefits. With changing eating habits, increased awareness of the health benefits associated with strawberry, it is considered a valuable food in the diets of millions of people across

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the world and an individual should eat a serving of eight strawberries a day (Bandara, 2021). Demand of strawberry is increasing in the fresh market as well as in the processing industries for making various processed edible products such as juice, chutney, squash, jam, jellies, milkshakes, pie, ice cream, and chocolate in many parts of the world (Simpson, 2018).

China, the United States, Mexico, Turkey, and Spain are the top five countries that produce the most strawberries. In India, it is grown in Haryana, Punjab, Uttar Pradesh, Madhya Pradesh, Karnataka, Tamil Nadu, Rajasthan, Uttarakhand, and Himachal Pradesh. Strawberries are commercially propagated through runners (Bai *et al.*, 2023). Several high-yielding and large-fruited varieties such as Chandler, Pajaro, Etna, Sweet Charlie, Selva, Douglas, Confictura, Dana, Belrubí, Gorella, and Addie are introduced from Europe and North America. Some day neutral cultivars like Selva, Majestic, Phenomenal, Brighton, Etna, and Fern are well suited to the Indian conditions (Pramanick and al., 2013). In Himachal Pradesh varieties like Camarosa, Sweet Charlie, Chandler, Winter Down, Rania, San Andreas, Nabils, Brighton and Douglas are popular among the farmers.

Addressing priority of the State of Himachal Pradesh

Strawberry is a widely commercialized fruit that has the ability to provide economic benefits to growers by fetching better prices of Rs 200 to Rs 300 per kg when sold early in the season (Chaulagain *et*

al., 2022). The net profit from 800 m² land after 6 years may vary from Rs 4.19 lakhs in the hills to Rs 8.48 lakhs per season in the plains (Pramanick *et al.*, 2013). Farmers in subtropical and tropical regions such as Delhi, Haryana, Punjab, Maharashtra, Karnataka, and Uttar Pradesh profitably cultivate strawberries during the winter months, sourcing their planting material (Runners) from the hills of Himachal Pradesh and Uttarakhand (Bai *et al.*, 2023).

The climate of the lower hills of Himachal Pradesh is excellent for producing high-quality fruits, while the climate of the medium and high ranges is ideal for producing top-quality runners. It generates enough revenue to support farmers and resilient rural communities. In addition to income from strawberry fruits, farmers in the hills can earn money through the production of planting material for winter plantings in the plains. Strawberries are easy to cultivate (Figure 1), and women in rural Himachal Pradesh can easily undertake strawberry cultivation and runner production, resulting in Socio-economic advancement and sustainable livelihoods of rural women via the strawberry runner production and the development of employment possibilities in the community.

Author contribution statement

AK, DPS & PK- conceive the idea; AK & PK- prepared the draft manuscript; AK, PK & DPS - edited the manuscript; All the authors of article have read the manuscript and approved it.

Conflict of interest

The authors of the article affirm no competing interest.



Figure 1: - Overview of strawberry cultivation and runner production

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Role of Drone Technology in Transforming Fruit Production

Chandan Kumar Rout and Pramod Kumar Panda

Abstract

Drone technology is transforming the agricultural sector, particularly in fruit production. These unmanned aerial vehicles (UAVs) facilitate precision farming, crop monitoring, and various other tasks that enhance efficiency, reduce costs, and promote sustainability. This article explores the advantages, challenges, and potential of drone technology in fruit farming. By analyzing its impact, we aim to provide insight into the evolving role of drones in modern agriculture.

Introduction

The rising global demand for fruits, driven by population growth and increased health awareness, has necessitated the adoption of advanced agricultural technologies. Among these innovations, drones have emerged as a valuable tool in fruit production. Equipped with high-tech sensors, cameras, and GPS systems, drones assist in crop surveillance, spraying, and even artificial pollination with remarkable accuracy. This article examines the transformative potential of drone technology in fruit farming, emphasizing its benefits, limitations, and future possibilities.

Understanding Drone Technology

Drone technology refers to the use of UAVs integrated with sensors, cameras, and GPS for remote or automated tasks. In agriculture, drones are utilized for crop monitoring, spraying, planting, and



data collection. These devices efficiently survey large farmlands, capturing high-resolution images and gathering crucial data that helps farmers make informed decisions regarding crop management.

Advantages of Drone Technology in Fruit Production

Precision Agriculture: Drones provide detailed insights into crop health, soil conditions, and moisture levels, enabling precise application of fertilizers, pesticides, and water, reducing waste and enhancing yield.

Cost Reduction: Automating labor-intensive tasks like spraying and monitoring decreases reliance on manual labor, lowering production costs.

Time Efficiency: Drones cover large areas swiftly, delivering real-time data for timely decision-making.

Environmental Sustainability: By optimizing chemical and water usage, drones help reduce environmental harm.

Enhanced Crop Health Monitoring: Advanced

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sensors enable early detection of diseases, pests, and nutrient deficiencies, allowing prompt intervention.

Challenges of Drone Technology in Fruit Production

High Initial Investment: The cost of purchasing and maintaining drones can be a financial burden, especially for small-scale farmers.

Regulatory Restrictions: Drone usage is subject to stringent regulations that vary by region, potentially limiting widespread adoption.

Technical Knowledge Requirement: Effective operation and data interpretation demand specialized skills and training.

Battery Limitations: Short battery life restricts drone usage in extensive farming operations.

Weather Sensitivity: Adverse weather conditions like strong winds and rain can affect drone performance.

Applications of Drone Technology in Fruit Production

Crop Surveillance: Drones equipped with multi-spectral and thermal cameras provide high-resolution images of fruit orchards, enabling precise monitoring of crop health. These images reveal variations in plant vigor, nutrient deficiencies, pest infestations, and disease outbreaks. By analyzing this data, farmers can detect stressed areas and take corrective measures before the damage spreads, thereby improving overall crop health and yield. Additionally, drones allow for real-time monitoring, reducing the reliance on manual



field inspections, which can be time-consuming and labor-intensive.

Precision Spraying: Traditional spraying methods often lead to uneven chemical application, wastage and environmental contamination. UAVs equipped with advanced spraying systems can deliver pesticides, herbicides, and fertilizers with pinpoint accuracy. These drones use variable rate application (VRA) technology to apply chemicals only where needed, reducing costs and minimizing environmental impact. Precision spraying not only improves efficiency but also enhances worker safety by reducing exposure to harmful chemicals. In fruit orchards with dense canopies, drones can navigate difficult-to-reach areas, ensuring uniform coverage.



Automated Planting: Some modern drones are designed for automated seed dispersal, making them valuable tools for reforestation projects and planting in inaccessible or difficult terrains. In fruit production, this technology can be adapted for planting cover crops, which help improve soil fertility, prevent erosion, and enhance biodiversity. Automated planting via drones also reduces the need for labor-intensive manual seeding, making the process more efficient and cost-effective. Moreover, the precise seed placement by drones ensures optimal germination rates and uniform plant growth.



Irrigation Optimization: Water management is a

critical factor in fruit production, as both excess and insufficient irrigation can negatively affect crop health. Drones equipped with infrared



sensors and thermal imaging cameras can assess soil moisture levels and detect areas experiencing drought stress. This data helps farmers optimize irrigation schedules, ensuring that fruit trees receive adequate water without overuse, thus promoting sustainable water conservation. Additionally, integrating drone-collected data with smart irrigation systems allows for automated, data-driven irrigation adjustments, enhancing water-use efficiency and reducing operational costs.

Artificial Pollination: Pollination is essential for fruit production, yet declining bee populations pose a significant challenge. UAVs fitted with specialized pollination devices can help address this issue by dispersing pollen across orchards in a controlled manner.



These drones mimic the natural pollination process by targeting specific flowers with precision, ensuring effective fertilization and improved fruit set. This technology is particularly beneficial for crops that require cross-pollination or for fruit orchards located in regions with pollinator shortages. Future advancements in drone-based pollination may include AI-driven navigation and robotic arms for even more efficient pollination methods.

Harvesting: Drones revolutionize fruit harvesting in

orchards by autonomously picking mature fruits with precision, reducing labor costs and time. Equipped with AI and grippers, they identify and pluck fruits



gently, minimizing damage. Drones access hard-to-reach areas, enhancing efficiency. This technology ensures faster, cost-effective and sustainable harvesting, transforming traditional orchard management.

Yield Forecasting: Accurate yield estimation is crucial for market planning, inventory management, and financial forecasting. Drones equipped with machine learning algorithms and advanced imaging techniques analyze crop canopy size, fruit count, and fruit maturity levels to predict yields with high accuracy. This data-driven approach helps farmers optimize harvest schedules, reduce post-harvest losses, and improve supply chain efficiency. By integrating yield forecasting with market trends, fruit producers can make informed decisions about pricing and distribution, ultimately maximizing profitability.

Future Prospects of Drone Technology in Fruit Production

Autonomous Farming: The advancement of drone technology may lead to fully automated orchards where drones collaborate with other smart farming tools.

AI Integration: The combination of artificial intelligence and drones will enable more sophisticated data analysis, improving efficiency and decision-making.

Swarm Technology: Coordinated drone swarms could enhance agricultural processes such as spraying and monitoring.

Enhanced Sensor Technology: Future drones may feature improved sensors capable of detecting a broader range of crop health indicators.

Global Adoption: As costs decline and regulations evolve, drone usage in fruit farming is likely to expand worldwide.

Advanced Pollination Methods: Future UAVs may incorporate robotic arms or specialized brushes to replicate natural pollinators more effectively, boosting fruit yields and quality.

Conclusion

Drone technology is revolutionizing fruit production by enhancing efficiency, reducing costs, and promoting sustainability. Despite challenges such as high initial costs and regulatory barriers, the benefits of drones in modern agriculture are undeniable. As technological advancements continue, drones are expected to play an even greater role in sustainable and efficient fruit farming, paving the way for future innovations in agriculture.

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Role of Artificial Intelligence in Plant Breeding

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Abstract

Artificial intelligence (AI) is a broad term that can be regarded as a focus on building programs that use computers to train automated machines to perform functions similar to or better than humans. AI is emerging as a revolutionary field, with significant opportunities for molding modern crop development, and is widely utilized indoors for plant research. AI applications in plant sciences include plant identification, disease detection, forecasting yields, phenotyping, and precision agriculture. Also it provides massive computational power, as well as numerous new tools and techniques for future breeding.

Introduction

Since the commencement of the plant breeding process, which began with crop domestication, new methodologies mediated by diverse advances in technology are constantly being enriched in research to boost the speed, accuracy, and precision in plant breeding. However, considering growing populations, limited arable land, and alterations in the climate, these have needed more precise, high-throughput techniques that can mediate in developing agricultural crop cultivars. The ultimate objective of AI is to develop some elements of human intelligence through computers. In the context of plant phenotyping, technologies powered by AI automate the estimation and evaluation of plant traits, providing scientists with an improved comprehension of plant growth and adaption mechanisms.

AI and Plant Breeding: AI is a remarkable high-tech system that presents unlimited opportunities in terms of agricultural applications; thus, this opens up new vistas for digital breeding. It is currently used to speed the process of breeding novel plant varieties, including high-throughput genomics and phenomics to advanced breeding. Also this approach is increasingly being applied to genomic prediction, genomic selection, and marker-assisted selection. Phenotypic analysis is critical for crop breeding, yet they encounter substantial challenges that prevent their utilization. Conventional plant phenotyping approaches have long been seen as a constraint in crop breeding due to their restricted data collection capability. However, the recent advent of plant phenomics indicates a major change in this paradigm. Phenomic platforms coupled with powerful imaging devices have the potential to transform

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large-scale phenotyping across multiple plant characteristics and environmental situations. Such platforms can make use of either static or mobile sensors. Towers and other stationary platforms are frequently utilized to observe growth stages due to their simplicity and ease of maintenance. To demonstrate, digital cameras placed on a permanent phenotyping tower were used for tracking plant growth, nutrient levels, leaf area index, and the presence of bugs.

Genomic prediction using AI: For genomic prediction in the agricultural sector, the interpretability of AI models, additionally referred to as explainable AI. Being capable explain predictions enables the rapid development of DNA markers for breeding, perhaps leading to more robust and resilient crop kinds. It also increases breeders' confidence in AI-based judgments, which is crucial for their implementation in breeding programs. In addition, based on the DNA methylation patterns of maize crops developing under stress, researchers have employed AI techniques to identify and define genomic areas, distinguishing between functional genes and pseudogenes.

Gene Function Analysis using AI: Several machine learning methods and techniques are available for various types of computational biology analysis, such as a protein-coding gene identification, cis-regulatory element recognition, expression of genes, subcellular location, protein-protein interactions, gene ontology, pathways of metabolism, traits, and genomic forecasting.

A few investigations used different methods of machine learning to identify the genes responsible for stress caused by abiotic factors. The information gained from ML models open the path for developing hypothesis that can be tested, such as identifying genomic regions, potential genes, or residues of proteins for additional experimental validation.

Applications of AI in gene editing: Mutagenesis, hybridization, and transgenic breeding are some of the traditional breeding strategies that have helped to improve agricultural production and quality significantly. However, they have disadvantages such as long breeding cycles, high unpredictability, low precision, partial gene function loss, and challenging screening techniques. The advancement of genome sequencing technologies has created opportunities for precise and efficient molecular breeding, which has gained popularity among breeders. Notably, the refining of CRISPR/Cas9 technology has changed breeding efforts and considerably expanded studies into crop quality enhancement. AI is being employed to evaluate structural data and improve protein functionality. AlphaFold2, a highly precise protein structure prediction tool, is a peculiar application of artificial intelligence in biology that is currently used as a standard 'infrastructure' for biological research. AI models are also being used to develop guide RNAs (gRNAs) for CRISPR-Cas systems. Tools like as DeepCRISPR, CRISTA, and DeepHF can estimate the best guide RNAs (gRNAs) for a given target sequence.

Conclusion

AI technologies have the potential to change public sector plant breeding projects like the One CGIAR (Consultative Group for International Agricultural Research) program. AI-enabled breeding technologies accelerate the breeding procedure by utilizing powerful computing and analysis methods. The potential of AI in discovering genes and allele mining is well understood; nevertheless, the ultimate promise of AI is in assisting with the biological design of future agricultural cultivars that are well suited to projected conditions. This transformation would change the way breeding decisions are made, perhaps improving global food security and promoting agricultural sustainability.

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Kalanamak Rice: Special Kinds of Rice

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Abstract

The importance of preserving landrace rice variety kalanamak, also known as Buddha rice, is associated with Lord Buddha and has a unique aroma and quality. Its origins date back thousands of years and is mainly cultivated in a specific region in eastern Uttar Pradesh. Kalanamak is a naturally scented rice with a long history of cultivation and cultural significance, but it is facing extinction due to low yield. To save the kalanamak rice variety, efforts are needed to improve its grain quality and yield, promote and market its unique traits, and conserve its genetic diversity and cultural heritage. This rice was chosen as one of these nutri-crops due to its high levels of Iron and Zinc, which help to prevent diseases caused by nutrient deficiencies, and the low Glycemic index of kalanamak rice holds the first position among other rice varieties.

Introduction

Rice is an essential cereal crop that provides food security and livelihood to millions of people around the world, especially in Asian countries. Aromatic rice is highly valued in both domestic and international markets due to its distinct aroma, texture, and flavor. Among the various types of aromatic rice grown in India, Kalanamak rice is one of the most well-known and has been cultivated for thousands of years (Roy *et al.*, 2018). The name kalanamak rice derives from its black husk (Kala Namak, meaning black salt in Hindi), which is a distinguishing characteristic of this variety. Kalanamak rice has a unique combination of high aroma, high iron, high zinc, and high protein content, making it a highly nutritious grain. This rice variety is also rich in antioxidants like anthocyanins, which

are beneficial in preventing heart disease and improving skin health. However, over the years, the cultivation of kalanamak rice has declined drastically, leading to a decline in its grain quality and yield. Owing to its nutritional value and cultural significance, preserving and promoting the cultivation of kalanamak rice is crucial. Efforts to conserve and promote this unique rice variety not only support local livelihoods but also contribute to global food security and nutrition. Acreage under the cultivation of this variety has declined sharply, pushing it towards extinction, for reasons including:

- ✓ Panicle blast epidemics in 1998 and 1999
- ✓ Tall stature of the crop causing lodging
- ✓ Long time harvest (6 to 7 months)
- ✓ Poor quality seeds and research support

Kalanamak was grown widely in Kapilvastu

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and the Tarai belt of Uttar Pradesh, which comprised districts viz., Sidharth Nagar, Sant Kabir Nagar, Maharajganj, Basti, Gonda, and Gorakhpur. Until the 1990s, the variety made up more than 10% of the total rice cultivation area in Sidharth Nagar.

History of Kalanamak: Kalanamak rice has been cultivated since the Buddhist period (600 BC). Kalanamak grains were found in the excavation of Kapilvastu. Kapilvastu, part of the Kingdom of King Śuddhodana, father of Gautama Buddha, is located in Terai, Nepal. During the excavation of Aligarhwa, carbonized rice grains resembling Kalanamak were recovered. The first effort to conserve Kalanamak rice was made by Englishmen William Pepe, J H Hemprey, and Edcan Walker (Jamindars of Alidapur, Birdpur, and Mohana) during the British Raj. They built reservoirs at Bajha, Marthi, Moti, and Majhauri to produce Kalanamak. They produced this variety for their consumption and transported it to England from Uska-bazar mandi, passing through Dhaka (now in Bangladesh). Due to increasing demand, the British captured the land around Kapilvastu and established Birdpur and Alidapur states. They produced Kalanamak through bonded labor and exported it to Britain. When Gujrati businessmen came to know about this business potential, they formed a *mandi* at Uska-bazar to export Kalanamak. British “shopkeepers” built a rail route to carry rice via rail to counter them. After independence, Uska-bazar mandi became nonfunctional due to negligence and reservoirs gathered silt. This led to a fall in the production of

Kalanamak.

Geographical Indication Tag (GI) and areas of cultivation: Kalanamak rice was granted the Geographical Indication (GI) Tag in 2012 by the Government of India. A geographical area was defined where Kalanamak rice can be produced. Kalanamak rice grown only in this area can be labelled as Kalanamak rice. The GI tag is used for agricultural, natural and manufactured goods. The geographical area for Kalanamak rice lies between 26° 42' North to 27° 75' North Latitude and 81° 42' to 83° 88' East Longitude in Uttar Pradesh. Kalanamak Rice is approved for 11 districts of Zone 7 of Uttar Pradesh. These 11 districts are located in the divisions of Gorakhpur (Deoria, Gorakhpur, Mahrajganj, Siddharth Nagar districts), Basti (Basti, Sant Kabir Nagar, Siddharth Nagar districts), and Devipatan (Bahraich, Balrampur, Gonda, Shravasti districts). The aroma of Kalanamak rice is said to be Buddha's gift. It is stronger than all Basmati varieties. It elongates after cooking, which is one of its most important qualities traits. Cooked kalanamak is softer and fluffier than other rice varieties. Amylose content is close to 20% as compared to 24% and higher in Basmati. High amylose levels tend to make the rice cook firm and dry. Rice with a medium amylose content, between 16% and 22%, usually cooks softer and the grains stick together more readily.

Characteristics of Kalanamak rice

Aromatic Fragrance: Kalanamak rice is often referred to as the “black rice” or “scented rice”

because of its extraordinarily pleasant aroma. The scent is described as a blend of jasmine and other floral notes, making it highly coveted for gourmet cooking.

Appearance and Color: Unlike white rice, Kalanamak rice has a slightly darker appearance. It has a brownish-black hue, particularly when harvested, and the grains are medium to long. The dark color is one of its distinguishing features, and it remains even after cooking.

Texture and Taste: Kalanamak rice has a soft, sticky texture once cooked, but it is not overly sticky. It has a nutty flavor with a subtle sweetness, making it a favorite for a wide range of dishes, including traditional Indian recipes like biryanis and pilafs. Its unique taste makes it an ideal pairing with rich curries and other complex flavors.

Cultural Significance: Kalanamak rice has cultural importance in various regions of India. It is often used in festivals, religious ceremonies and weddings, adding a special touch to traditional feasts. In some areas, it is considered a symbol of prosperity.

Comparison between Kalanamak and White rice

Kalanamak Rice

Nutritional Value: Rich in iron and zinc, with a low glycemic index, making it suitable for individuals with diabetes. It also has a higher protein content.

Flavor and Aroma: Possesses a distinct aroma and a slightly sweet, nutty flavor.

Texture: Cooked kalanamak rice is fluffy, soft, and easily digestible.

Health Benefits: The high iron and zinc content,

coupled with its low glycemic index and high protein content, contribute to its health benefits.

Other Notable Features: Some research suggests it may help prevent Alzheimer's disease and is often considered auspicious for marriages.

White rice

Nutritional Value: Generally lower in micro-nutrients compared to kala namak rice, though it's still a source of carbohydrates and some vitamins.

Flavor and Aroma: Typically has a mild, neutral flavor and a less distinct aroma compared to kalanamak rice.

Texture: Cooked white rice can vary in texture depending on the type, but it often has a lighter, fluffier texture.

Health Benefits: While a source of carbohydrates, white rice can be lower in fiber and other nutrients than some other rice varieties.

Other Notable Features: White rice is a common staple food and is readily available.

Nutritional Profile of Kalanamak

Kalanamak rice is a rice variety known for its high nutritional value, particularly its protein content and iron and zinc levels. It also boasts a low glycemic index, making it a good option for those managing blood sugar. The rice is rich in micronutrients like iron, zinc, and antioxidants, and is also a good source of fiber. The nutritional profile of kalanamak is given below:

Nutritional Components

Protein: Kalanamak rice has a significantly higher protein content compared to common rice varieties,

sometimes double the amount.

Iron: It's a good source of iron, which is essential for red blood cell production and oxygen transport.

Zinc: Kala Namak rice is rich in zinc, which is crucial for immune function and wound healing.

Antioxidants: It contains antioxidants like anthocyanin, which may help protect against heart disease and improve skin health.

Fiber: The presence of fiber aids in digestion and can help with satiety.

Low Glycemic Index: With a low glycemic index (GI), it's a suitable choice for individuals with diabetes or those looking to manage their blood sugar levels.

Micronutrients: Kalanamak rice is also a source of other essential minerals like magnesium, copper, and calcium.

Other Notable Features

Unique Flavor: It has a distinctive aroma and flavor, making it a culinary delight.

Disease Resistance: Kalanamak rice is known for its resistance to certain rice diseases, like panicle blast and stem rot.

Versatility: It can be used in various dishes, including pulao, kheer, salad, and stir-fry. Overall, Kalanamak rice offers a comprehensive nutritional package, making it a valuable addition to a healthy diet.

Nutritive value of Kalanamak rice

The Kalanamak rice is rich in micronutrients like Iron and Zinc, has a low glycemic index, thus better for diabetic people, and also has higher protein

content when compared to other paddy varieties.

Particulars	General Rice	Kala namak Rice
Amylose	24%	19-20%
Protein	5-6%	10%
Fat	0.52	0.51
Iron	1 mg	3 mg
Zinc	0.1 mg	0.4 mg
Carbohydrate	88%	87.96%
Glycemic Index	85%	49%

Source: agriculture.vikaspedia.in



Source: Grain of Kalanamak before threshing and after threshing (<https://www.prdf-agri.com>)

Constraints of Kalanamak rice production

The production of Kalanamak rice, a specialty aromatic variety grown primarily in the Terai region of Uttar Pradesh, India, faces several constraints that hinder its large-scale cultivation and commercialization. These constraints affect both the farmers who grow it and the overall supply chain. Below are the primary constraints in the production of Kalanamak rice:

Limited Geographic Area

Narrow Cultivation Zones: Kalanamak rice is grown in specific regions, primarily in the Terai belt of Uttar Pradesh and its cultivation is geographically restricted. The rice thrives in the unique soil and climatic conditions of this region, which limits the areas where it can be produced.

Climate Dependence: Kalanamak rice is sensitive to climate and requires specific temperature ranges, monsoon rains, and soil conditions.

If these conditions are not met, the rice may not grow well, leading to low yields or poor-quality crops.

Low Yields

Increased Labor and Time Investment: Kalanamak rice is typically grown using traditional, labor-intensive methods, which leads to lower productivity per hectare. This is in contrast to high-yielding varieties that use modern farming techniques and chemical fertilizers to boost production.

Yield Variability: The yield of Kalanamak rice can be highly variable, depending on factors such as soil quality, water availability, and pest infestations. This makes it difficult for farmers to predict and stabilize their production levels year-on-year.

Vulnerability to Pests and Diseases

Susceptibility to Pests: Kalanamak rice is grown organically, with minimal use of chemical pesticides, which makes it more vulnerable to pests and insects that can damage crops, such as rice weevils, leafhoppers, and stem borers.

Disease Risks: Without the use of modern chemical controls, Kalanamak rice is also susceptible to diseases like blast, brown spot, and rice tungro virus, which can significantly reduce crop yields and quality.

Weed Management: Organic farming practices make it more difficult to manage weeds effectively, which can compete with the rice plants for nutrients, light, and water.

High Cost of Cultivation

Labor-Intensive Farming: Traditional farming techniques require more manual labor compared to modern mechanized methods, driving up the cost of cultivation. The use of organic farming practices, while beneficial for health and the environment, also increases costs due to the need for more intensive management of the crop.

Fertilizers and Inputs: Since Kalanamak rice is often grown organically, it requires natural fertilizers and compost, which can be more expensive and less effective than chemical alternatives. Moreover, the reliance on traditional practices for irrigation and pest management further raises production costs.

Small-Scale Farming: Most Kalanamak rice farms are small-scale, and economies of scale are not achieved, which makes it more costly to grow compared to larger, more industrialized rice production systems.

Water Management and Irrigation Constraints

Dependency on Monsoons: Kalanamak rice farming relies heavily on the monsoon season for water. Any disruption in rainfall patterns, such as delayed or insufficient rains, can negatively affect the crop's growth, leading to poor yields or crop failure.

Irrigation Challenges: In regions where rainfall is inconsistent, irrigation systems are not always efficient and groundwater sources may be overused, further depleting water resources. Farmers may struggle to maintain consistent water availability for the crops, which is vital for their proper growth.

Soil Fertility and Land Degradation

Soil Health: The quality of soil in certain areas may degrade over time due to overuse or poor soil management practices. Rice, particularly in the case of Kalanamak, requires rich, well-drained soils with good organic content. Continuous cultivation without proper soil management can lead to nutrient depletion and reduced yields.

Sustainability of Organic Farming: While organic farming practices are beneficial for the environment, they require proper soil management techniques to maintain long-term fertility. If farmers do not follow sustainable practices, they may face issues with soil erosion and nutrient imbalance, which could hinder future rice production.

Market Challenges and Pricing Issues

Lack of Market Awareness: Despite its distinct aroma and health benefits, Kalanamak rice is still relatively unknown outside the regions where it's grown. This results in lower demand and limits the profitability of growing this specialty rice.

Price Fluctuations: Farmers often face price fluctuations for Kalanamak rice due to market demand and supply dynamics. If demand is low, they may not receive fair compensation for their efforts, making it economically unviable.

Adulteration: There is a risk of adulteration in the market, where cheaper, non-aromatic rice varieties are mixed with Kalanamak rice and sold under its name. This undermines the value of genuine Kalanamak rice and can hurt its reputation and price in the market.

Inadequate Research and Development (R&D)

Limited Scientific Research: There is relatively little research on improving the productivity, disease resistance, and climate resilience of Kalanamak rice. As a result, there is a lack of improved seed varieties, crop management practices, and technological advancements that could help address some of the challenges faced by farmers.

Breeding Programs: While other rice varieties, like Basmati, have benefited from extensive breeding programs, Kalanamak rice has not seen as much investment in breeding for traits like higher yield, resilience to pests, or climate adaptability.

The way to promote Kalanamak rice

Promoting Kalanamak rice effectively requires a combination of increasing awareness, creating demand, and improving market access. Given its unique characteristics and cultural significance, several strategic approaches can help increase its visibility, value, and consumption. Below are the ways to promote Kalanamak rice successfully:

Raising Awareness and Education

Highlight Unique Qualities: Promote Kalanamak rice's distinctive fragrance, flavor, and nutritional benefits to attract consumers. Use social media, blogs, and culinary platforms to spread knowledge about the rice's exceptional aroma, health benefits, and its historical and cultural relevance.

Educate Consumers: Many people are not aware of the unique qualities of Kalanamak rice.

Educating consumers about its health benefits (e.g., low glycemic index, rich in fiber) and its aromatic properties can help differentiate it from other rice varieties. Cooking demonstrations, recipe sharing, and informative content (articles, videos, etc.) can help showcase its potential.

Cultural Significance: Emphasize Kalanamak rice's role in local festivals, traditional feasts, and cultural rituals. Position it as not just a food product but a part of Indian heritage and local traditions, especially for people seeking authentic and indigenous food experiences.

Branding and Packaging

Premium Branding: Kalanamak rice can be marketed as a premium product due to its aromatic quality, organic nature, and limited cultivation. A strong branding campaign that emphasizes its premium, natural, and organic attributes can attract health-conscious consumers.

Innovative Packaging: Invest in high-quality, eco-friendly packaging that preserves the aroma of the rice and communicates its premium nature. Packaging can include information about the rice's origin, the benefits of choosing Kalanamak rice, and its GI (Geographical Indication) certification to build credibility.

Appealing to Niche Markets: Kalanamak rice could be marketed to high-end gourmet food stores, organic food markets, and ethnic grocery stores that cater to consumers who are willing to pay a premium for unique and authentic products.

Expanding Market Reach

Domestic Market Expansion: Currently, Kalanamak rice is popular in specific regions, but it needs to be marketed across India. Regional food festivals, online marketplaces, and direct-to-consumer platforms (e.g., through e-commerce websites) can help expand its reach to urban and semi-urban markets across India.

International Markets: Position Kalanamak rice as an international delicacy by exploring export opportunities. The growing global interest in organic, healthy, and aromatic rice varieties provides an avenue for exporting Kalanamak to countries with a demand for specialty rice, such as the Middle East, Europe, and North America.

Food Service Industry: Promote Kalanamak rice to chefs and the food service industry (hotels, restaurants, catering services) as a high-quality rice option for making gourmet dishes, biryani, pilafs, or traditional Indian dishes that require aromatic rice. This can create demand for the rice in fine dining or ethnic cuisine restaurants.

Promoting the Health Benefits

Nutritional Campaigns: Highlight Kalanamak rice's nutritional value in marketing campaigns, focusing on aspects like its low glycemic index, high fiber content, and antioxidant properties. These are appealing to health-conscious consumers, especially those who are looking for organic or diabetic-friendly food options.

Target Specific Demographics: Position the rice as an ideal choice for diabetic patients, health-conscious individuals, and organic food enthusiasts.

Collaborate with nutritionists, wellness influencers, and health bloggers to advocate for the benefits of consuming Kalanamak rice.

Sustainability and Organic Farming

Sustainability Campaigns: Promote Kalanamak rice as an environmentally friendly and sustainable product, as it is typically grown using traditional, organic farming methods without chemical fertilizers and pesticides. This is an attractive selling point for environmentally conscious consumers who prioritize sustainable and ethical food choices.

Support for Small Farmers: Communicate how purchasing Kalanamak rice directly supports local farmers in the Terai region, who often use traditional and organic farming methods. This aspect can resonate with consumers who prioritize fair trade and supporting local economies.

Government and NGO Support

Government Initiatives: Collaborate with government agencies to promote Kalanamak rice through agriculture development schemes, subsidies, and financial incentives for farmers. Governments can also help by promoting the rice at national and international food expos, agriculture fairs, and export platforms.

NGO Partnerships: Work with NGOs to train farmers in best practices for cultivating Kalanamak rice more efficiently, using sustainable farming techniques, and improving the marketability of the rice. NGOs can also assist in certification processes, making it easier to scale production.

Health Benefits of Kalanamak

Kalanamak rice offers several health benefits due to its unique nutritional profile and low glycemic index. It's known for being a good source of protein, iron, and other essential minerals, and its low GI helps manage blood sugar levels. The key benefits of kalanamak rice are:

Low Glycemic Index (GI): Kalanamak rice has a low GI (around 52), which means it releases glucose slowly into the bloodstream, preventing rapid spikes in blood sugar. This is beneficial for individuals with diabetes or those looking to manage their blood sugar levels.

High Protein Content: It contains a significant amount of protein, almost double that of some other rice varieties, making it a good source of protein for muscle growth and repair.

Rich in Micronutrients: Kalanamak rice is packed with essential micronutrients like iron, zinc, and magnesium, which are crucial for various bodily functions, including boosting immunity and maintaining energy levels.

Potential for Improved Skin Health: Some research suggests that the antioxidants in Kalanamak rice, like anthocyanins, may have benefits for skin health.

Conclusion & future perspectives

Kalanamak variety of rice is a historical, naturally scented variety cultivated since the Lord Buddha period. And now, kalanamak rice has become an identity of the North-Eastern plain of Uttar Pradesh. Kalanamak rice is now the heritage

of Eastern Uttar Pradesh and has also got a GI tag and registered in the Sidharth Nagar district, under the Government of Uttar Pradesh, which will be very helpful in conserving this variety. Currently, with the help of government Participatory Rural Development Foundation Gorakhpur roused the occasion to save kalanamak from extinction, to bring back its old glory and Aroma. It will be very beneficial to farmers for cultivating the kalanamak variety and ultimately contribute to agricultural economics. Kalanamak rice, a heritage grain, has a promising future driven by increasing global demand for organic and heritage foods. Its unique characteristics, like being naturally scented and potentially better for certain health conditions, offer market advantages. However, the future of Kalanamak cultivation and consumption depends on addressing challenges like low yield, ensuring authenticity, and promoting sustainable practices

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Physical Methods of Plant Disease Management

H. P. Chaudhari, L. S. Chaudhary and S. S. Kansara

Abstract

Physical methods for disease control are gaining popularity as eco-friendly alternatives to fungicides for managing seed and soil-borne pathogens. These methods, which leave no harmful residues and do not pollute the environment, have been explored since the early 19th century. Techniques such as hot water, hot air, steam, and solar heat treatments have been employed to inactivate pathogens without damaging host tissues. Hot water treatment, for example, has successfully controlled diseases like loose smut in cereal grains. Similarly, hot air and aerated steam treatments have been effective in managing diseases in crops such as sugarcane ratoon stunting Disease and citrus greening. Soil solarization, using polyethylene sheets to harness solar energy, has proven effective against various fungal and nematode diseases. Other physical methods include refrigeration, radiation, drying, burning, and flooding, each offering unique advantages in reducing or eliminating pathogens. These methods provide viable options for integrating into disease management programs to ensure sustainable agricultural practices.

Introduction

There is an increasing interest in using physical methods for disease control as alternative to fungicides for the management for seed and soil-borne pathogens, and for integration in disease management programs. They usually do not leave residues or pollute the environment. As early as 1832, Sinclair suggested that hot air treatment in an oven might control smuts of oats and barley. Gardeners in Scotland while treating the bulbs of different ornamental plants first employed hot water therapy. However, the credit for conclusively demonstrating the therapeutic nature of heat must go to Jensen, who successfully employed hot water

treatment for controlling loose smut of cereal grains and suggested that moisture played some role other than heat transfer. This method was followed in Demark and later adopted in US on the recommendation of Swingle in 1892 (Shavelle, 1979).

The principle

The scientific principle involved in heat therapy is that the pathogen present in seed material is selectively inactivated or eliminated at temperatures that are non-lethal to the tissues. The exact mechanism by which heat inactivates the pathogen is not fully understood. However, it is universally accepted that heat cause inactivation and

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immobilization of the pathogen. There are two schools of thoughts regarding inactivation of pathogen (viruses) by heat. One holds the opinion that the heat treatment stimulates enzymes that cause the degradation of virus, though according to Benda (1972) this has not been established. The others pursue the idea that heat causes loosening of bonds both in nucleic acid and the protein components of the virus. In the nucleic acid, when the bonds are disrupted the linear arrangement of nucleotides is disrupted and thus the virus loses infectivity. In proteins, the bonds holding the chains of amino acids may be destroyed. Disruption of bonds causes denaturing of protein molecules which become less soluble in water and finally leads to coagulation. The rate at which the pathogen is inactivated is determined by temperature and the duration of treatment. At constant temperature, the drop in the density of pathogenic inoculum is exponential.

The Methods

Physical Methods for Seed-borne Pathogens:

Some of the seed treating procedure do not involve the use of fungicides, the physical agents like hot water or hot air or steam is used to eliminate the seed-borne infection. These methods are successfully used in controlling certain internally seed-borne diseases like loose smut of wheat and systemically infected diseases caused by bacterial, virus, viral and phytoplasma. Following physical methods are employed for reduction and/or elimination of primary inoculums that may be present in seed or planting material:

Hot Water Treatment: Hot water treatment is widely used for the control of seed-borne pathogens, especially bacteria and viruses. A list some important seed-borne diseases, claimed to have been controlled by hot water treatment is given in Table 1 and 2.

Hot Air Treatment: Hot air treatment is less injurious to seed and easy to operate but also less effective than hot water treatment. It has been used against several diseases of sugarcane. Singh (1973) claimed complete control of red rot in varieties Co 527, CoS 510, Bo 3 and Bo 32 by hot air treatment of 54°C for 8 hours. It is used for treating sugarcane stalks on commercial scale in Louisiana (Steiband Forbes, 1958) to control Ratoon stunting Disease (RSD). It is employed for treating canes which are soft and succulent. Lauden (1953) working in Mainland, US, reported that hot air treatment at 54°C for 8 hours effectively eliminates RSD pathogen without impairing the germination of buds. After 3 years, Steiband and Chilton (1956) confirmed Lauden's findings using thermocouple. Similarly, grassy shoot disease of sugarcane has been controlled by hot air at 54°C for 8 hours (Singh, 1968).

Steam and Aerated Steam: The use of aerated steam is safer than hot water and more effective than hot air in controlling seed-borne infections. The heating capacity of water vapour is about half that of water and 2.5 times that temperature control and no damage to seed coat of legumes. Besides its use in controlling sugarcane diseases, it has also been used against citrus greening (Cheema *et al.*, 1982).

Table 1: Control of seed-borne pathogens by Hot Water Treatment of seed

Crop	Disease	Causal organism	Treatment
Brassica spp	Black rot	<i>X. campestris</i> pv. <i>campestris</i>	50°C for 20 or 30 min
Cluster bean, Guar (<i>Cyamopsis tetragonoloba</i>)	Blight	<i>X. campestris</i> pv. <i>cyamopsidis</i>	50°C for 10 min
Cucumber (<i>Cucumis sativus</i>)	Seedling blight	<i>Pseudomonas syringae</i> pv. <i>lachrymans</i>	50°C and 75% RH for 3 days
Lettuce (<i>Lactuca sativa</i>)	Leaf spot	<i>X. campestris</i> pv. <i>Vitians</i>	70°C for 1 to 4 days
Peanut (<i>Arachis hypogea</i>)	Testa nematode	<i>Aphelenchoides arachidis</i>	60°C for 5 min after soaking for 15 min in cool water
Pearlmillet (<i>Pennisetum typhoides</i>)	Downy mildew	<i>Sclerospora graminicola</i>	55°C for 10 min
Potato (<i>Solanum tuberosum</i>)	Potato phyllody	<i>Phytoplasma</i>	50°C for 10 min
Rice (<i>Oryza sativa</i>)	Udbatta	<i>Ephelis oryzae</i>	54°C for 10 min
Safflower	Leaf spot	<i>Alternaria</i> spp.	50°C for 30 min
Teasel (<i>Dipsacus</i> spp.)	Stem nematode	<i>Ditylenchus dipsaci</i>	50°C for 1 hr or 48.8 °C for 2 hr
Tobacco (<i>Nicotiana tabacum</i>)	Hollow stalk	<i>Erwinia carotovora</i> pv. <i>carotovora</i>	50°C for 1 hr or 48.8 °C for 2 hr
Tomato (<i>Lycopersicon esculentum</i>)	Black speak	<i>Pseudomonas syringae</i> pv. <i>tomato</i>	52°C for 1 hr

(Chaube and Singh, 1990)

Table 2: Time and Temperature recommendations for Hot Water Treatment for Denematizing Planting Stocks (Reddy et al., 1983)

Nematode	Planting stalk	Time (min)	Temperature(°C)
<i>Aphelenchoides ritzemabosi</i>	Chrysanthemum stools	15	47.8
<i>Aphelenchoides fragariae</i>	Easter lily bulbs	60	44
<i>Ditylenchus dipsaci</i>	Narcissus bulbs	240	43
<i>Ditylenchus destructor</i>	Irish bulbs	180	43
<i>Meloidogyne</i> spp.	Cherry rootstocks	5-10	50-51
	Sweet potatoes	65	45.7
	Peach rootstocks	5-10	50-51.1
	Tuberose tubers	60	49
	Grape rooted	10	50
	Cutting	30	47.8
	Begonia	30	48
	Tubers	60	45
	Caladium tubers	30	50
	Yam tubers	30	51
	Ginger rhizomes	10	55
	Strawberry roots	5	52.8
	Rose roots	60	45.5

Pathogen	Disease
<i>Anguina</i> sp.	Seed nematode of <i>Lolium rigidum</i>
<i>Claviceps paspali</i>	Ergot of <i>Paspalum dilatatum</i>
<i>Cuscuta</i> sp	Parasite of lucern
<i>Pseudocercospora herpotrichoides</i>	Eye spot of wheat
<i>Puccinia graminis</i>	Stem rust of <i>Poa pratensis</i>
<i>Septoria avenae</i>	Leaf blotch of oat
<i>Verticillium dahlia</i>	Wilt of potato and peppermint
<i>Claviceps purpurea</i>	Ergot of <i>Lolium perenne</i>
<i>Puccinia menthae</i>	Rust of peppermint
<i>Sclerotium oryzae</i>	Stem rot of rice

(Hardison, 1976; Palti, 1981)

Most frequent application of steam and aerated steam has been in greenhouses where steam also provides heat during cold seasons. As a gas, it moves readily through soil, in contrast to the slow, inefficient movement of water. Steam raises temperatures efficiently. As gaseous water molecules (steam) condense into a liquid they release much more latent heat than that given out as warm water cools (540 cal g⁻¹ relative to 1 cal g⁻¹). Aerated steam provides an opportunity to treat soil at temperatures lower than those possible with pure steam.

Moist Hot Air Treatment: This method is effectively used in sugarcane to eliminate grassy shoot disease. Initially the setts are exposed to hot air at 54°C for 8 hours, then exposed to aerated steam at 50°C for 1 hours and finally to moist hot air at 54°C for 2 hours.

Solar Heat Treatment: A simplest treatment has been devised in India to eliminate the pathogen of loose smut of wheat. Previously the hot water treatment was followed to eliminate loose smut. As the thermal death point of the fungus and the embryo are very close, extensive care should be taken to avoid killing of the embryo. Luthra in 1953, devised a method to eliminate the deep-seated infection of *Ustilago nuda*. The method is popularly known as solar heat or solar energy treatment.

Luthra's solar energy treatment: The seeds are soaked in cold water for 4 hours in the forenoon on a bright summer day followed by spreading and drying the seeds in hot sun for four hours in the afternoon. Then, the seeds are again treated with carboxin or

Carbendazim at 2 gm kg⁻¹ and stored. This method is highly useful for treating large qualities of the seed lots.

Physical Methods for Soil-borne Pathogens

It is well known that soil harbours a large number of plant pathogens and the primary sources of many plant pathogens happens to be in soil where dead organic matter supports active or dormant stages of pathogens. In addition, seed treatment does not afford sufficient protection against seedlings diseases and a treatment of soil around the seed is necessary to protect them. Soil treatment is largely curative in nature as it mainly aims at killing the pathogens in soil and making the soil 'safe' for the growth of the plant. Some of the commonly followed physical methods for soil-borne pathogens are discussed:

Soil solarization: Soil solarization: In this management tactics, the solar energy is preserved with the help of transparent polyethylene sheet to increase soil temperature (10-15 °C above normal temperature) enough to kill the most of the soil-borne pathogens and weeds also (Khulbe, 2000, Akhtar *et al.*, 2008). Soil solarization with transparent polyethylene sheet mulch (25 µ m) for 40 days was found effective for the control of collar and root rot of strawberry caused by *Sclerotium rolfsii* (Bhardwaj *et al.*, 2004). Fungal diseases such as damping-off, root rots, stem rots, fruit rots, wilts and blights caused by *Pythium* spp., *Phytophthora* spp., *Fusarium* spp., *S. rolfsii*, *R. solani*, *Sclerotinia sclerotiorum*, *T. basicola* and *Verticillium* spp. have been success-

fully managed by soil Solarization.

Nematode diseases such as *Ditylenchus dipsci*, *Globodera rostochiensis*, *Heterodera* spp., and *Meloidogyne* spp. have been successfully managed by soil solarization. Bacterial canker of tomato (*Clavibacter michiganensis* var. *michiganensis*) is successfully managed by Soil solarization for 1-2 months (Akhtar *et al.*, 2008).

Steam sterilization: Steam is passed through perforated pipes at a depth of 15 cm to sterilize the upper layers of soil. It is mostly practiced under glass house and green house conditions.

Hot Air Sterilization: Hot air is also passed through pipelines to sterilize the soil in the nursery areas.

Hot Water Treatment: It is mainly done in pot culture studies to kill the fungi and nematodes. The pots containing soil are immersed in boiling water at 98°C for 5 minutes or drenching boiling water @ 20 liters m⁻².

Other Physical Methods

Refrigeration

It is an accepted fact that the low temperature at or slightly above the freezing point checks the growth and activities of all such pathogens that cause a variety of post harvest diseases of vegetables and fruits. Therefore, most perishable fruits be transported and stored in refrigerated vehicles and stores. 'Cool Chains', refrigerated space from field to consumer's table is becoming very popular. Regular refrigeration is sometimes preceded by a quick hydro-cooling or air-cooling to remove the excess heat carried in them from the field to prevent

development of new or latent infections

Radiation: Electromagnetic radiations such as ultraviolet (UV) light, X-rays and Y-rays, as particulate radiations (α particles and β particles) have been studied in relation to management of post-harvest diseases of horticultural crops. Findings of experiments revealed that y-rays controlled post-harvest fungal infections in peaches, strawberries and tomatoes but doses of radiation required to kill pathogens, were found injurious to host tissues. More efforts and required in this area as radiation can be very effective in inactivating pathogens in larger stores or handling bulk material that cannot be heated for sterilization. Some plant pathogenic fungi (*Alternaria*, *Botrytis*, *Stemphylium*) sporulate only when they receive light in the ultraviolet range (below 360 nm). It has been possible to control diseases on greenhouse vegetables caused by species of these fungi by covering or constructing the greenhouse with a special UV - absorbing vinyl film that blocks transmission of light wavelengths below 390 nm.

Drying Stored Grains and Fruits: In presence of sufficient moisture, a variety of microflora already accompanying harvested grains nuts, etc. cause decay. Such decay, however, can be avoided if seeds and nuts are harvested when properly mature and then allowed to dry in the air or are exposed to sun. Maize downy mildew pathogen is seed borne. If the maize seeds are properly sun dried, the inoculum gets inactivated. Hot air can be used until the desired moisture is reached (about 12% moisture) before

storage. Subsequently, they are stored under conditions of ventilation, which do not allow build-up of moisture. Fleshy fruits (peaches, strawberries) should be harvested later in the day, after the dew is gone, to ensure that the fruits do not carry surface moisture during storage and transit, which could lead to decay by microorganisms.

Burning: Controlled burning may alter the environment and after plant disease response, providing both a temperature effect and a means of destroying the pathogen (Zentmyer and Bald, 1977). Parameter and Uhrenholt in 1975 introduced a new aspect of burning by demonstrating the smoke may kill a number of plant pathogens in tissues. According to Hardison (1976, 1980) burning is single most important practice in grass seed production in the Pacific Northwest. It was initiated to control the blind seed disease of perennial rye grass caused by *Gloeotinia temulenta*. It also effectively controlled *Claviceps purpurea* (ergot of rye), *Anguina agrostis* (seed nematode) and silver top. Fire can be applied to cereals in which inoculum can be destroyed after harvest or pasture grasses which can periodically be freed from inoculum before they make new growth. It has also been realized that the increasing success of non-tillage in some crops and the resultant problems of debris management can make burning an attractive and effective proposition. Diseases that have been successfully managed by burning or flaming crops residue are given in the Table 3.

Flooding: Flooding fields and orchards to reduce or

eliminate soil-borne inoculum of plant pathogens is an ancient practice. According to Kelman and Cook (1977) flooding has been recognized to be one of the key factors for the low incidence of soil-borne disease in Chinese agriculture. In lower Yangtze and South China, the plots where vegetables are grown, are pre-cultivated with one or two crops of rice or spinach, water chestnut, water bamboo or lotus (Willian, 1979) for the control of soil-borne pests.

Several explanations of the harmful effects of prolonged flooding on soil-borne pathogens have been suggested. Lack of oxygen may be involved in some cases or, more often perhaps accumulation of CO₂ in the soil. The survival of *F. oxysporum* f. sp. cubense in soil after 2 weeks depends on formation of chlamydospores, since the conidia are not apparently long lived in soil Newcombe (1960) found that CO₂ and flooded soil both largely inhibited chlamydospores formation whereas at first they stimulated the production of conidia. Consequently the fungus, although able to survive in banana plantation soil containing organic matter, is likely to die out in a fallow flooded field where organic matter is in short supply. Newcombe (1960) concluded that the main factor in the elimination of the fungus by flooding is a high CO₂ content in the flooded soil, CO₂ stimulates germination of conidia, presumably by overcoming the fungistatic factor present in soil but prevents the formation of chlamydospores so that the fungus dies out when the organic matter is exhausted.

A similar situation perhaps holds for other

Table 3: Plant Disease Control by Flooding

Pathogen	Disease
<i>Alternaria porri</i> f. sp. <i>Solani</i>	Alternaria blight of tomato and potato
<i>Aphelenchoides besseyi</i>	White tip of rice
<i>Meloidogyne</i> sp.	Root knot of celery
<i>Phytophthora parasitica</i> var. <i>nicotianae</i>	Black shank of tobacco
<i>Radopholus similes</i>	Burrowing nematode of banana
<i>Verticillium dahlia</i>	Wilt of cotton
<i>Alternaria dauci</i>	Blight of carrot
<i>F. oxysporum</i> f. sp. <i>Cubense</i>	Wilt of banana
Orobanche spp.	Phanerogamic plant parasite of several crops
<i>Sclerotinia sclerotiorum</i>	White mould of vegetables

(Stover, 1955; Roteim and Palti, 1969; Tarr, 1972; Palti, 1981)

Table 4: Plant Disease Control by Flooding

Pathogen	Disease
<i>Alternaria porri</i> f. sp. <i>Solani</i>	Alternaria blight of tomato and potato
<i>Aphelenchoides besseyi</i>	White tip of rice
<i>Meloidogyne</i> sp.	Root knot of celery
<i>Phytophthora parasitica</i> var. <i>nicotianae</i>	Black shank of tobacco
<i>Radopholus similes</i>	Burrowing nematode of banana
<i>Verticillium dahlia</i>	Wilt of cotton
<i>Alternaria dauci</i>	Blight of carrot
<i>F. oxysporum</i> f. sp. <i>Cubense</i>	Wilt of banana
Orobanche spp.	Phanerogamic plant parasite of several crops
<i>Sclerotinia sclerotiorum</i>	White mould of vegetables

(Stover, 1955; Roteim and Palti, 1969; Tarr, 1972; Palti, 1981)

soil borne fungi but few cases have been investigated (Tarr, 1972). A list of plant diseases that have been successfully controlled by flooding fields and orchards is given in Table 4.

Conclusion

The exploration of physical methods for disease control as alternatives to fungicides has gained traction due to their environmental benefits and lack of residue. Heat therapy, a pioneer technique dating back to the 19th century, remains a

foundational method, selectively inactivating pathogens without harming the host tissue. Physical treatments for seed-borne pathogens include hot water, hot air, steam, and solar heat, each with its unique efficacy and application. Similarly, soil-borne pathogen management employs techniques like soil solarization, steam sterilization, and flooding. Innovations like radiation and controlled burning further expand the arsenal against plant diseases. Collectively, these methods offer sustainable and effective strategies for integrated disease management, underscoring the importance of physical interventions in modern agriculture.

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Potential Underutilized Fruit Crops of North East Region

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Introduction

The North-East India is rich in fruit diversity and contains more than one-third of the country's total diversity. The region is bestowed with diverse topography, altitude, soil and climatic conditions creating favorable conditions for evolution and development of different wild species which are utilized by the tribal population of the region for nutrition and medicinal purposes. The term under-utilized crops refers to those crops which are neither grown in a commercial scale nor marketed widely. In recent years there has been renewed interest for these under-utilized fruit crops as they are rich source of nutrient, vitamin, mineral and possess nutraceutical properties. Many of these plants when analyzed for nutritive value are found to provide higher vitamin A, vitamin C, folic acid and antioxidant activities compared to common fruits and vegetables. Some of the potential under-utilized fruit crops of the region are discussed below.

***Elaeagnus latifolia* L. (syn. *Elaeagnus javanica* Blume):** It is found growing in Khasi and Jaintia hills, Meghalaya, India. It is an evergreen, large, spreading, woody shrub with rusty-shiny scales that are often thorny. Flowers are hermaphrodite and flowering takes place during September-December. Fruit is oblong in shape and is usually harvested during March-April at light pink coloured stage.

It contains a large, single seed which has very less viability. It was reported by Rymbai *et al.* (2016) that the fruits recorded TSS (11.9 %), acidity (2.8 %), vit. C (16-19.2 mg/100 g pulp), reducing sugar (4.0 %), total sugar (6.1 %), bcarotene (1.1 l g/100 g pulp), anthocyanin (16.2 mg/100 g pulp) and antioxidants (10.1 l g moltrolox g⁻¹). Fruits including seeds are consumed raw at all stages of fruit growth. Pickle, jam, jelly and refreshing drink is also prepared from the fruits by the indigenous tribes.

***Padus napaulensis* (Ser. ex DC.) Schneider (syn. *Prunus nepalensis* Hook., *Prunus nepalensis* (Ser. ex DC.) Steud.):** It is a member of Rosaceae family. It is found growing in Khasi and Jaintia Hills at an altitudes between 800 and 3000 m a.s.l. Trees are large, evergreen and can grow up to a height of 15-20 m. Flowering appears in October-November and purplish or blackish brown fruits mature during August-September. Wide variations in physical fruit traits, ranging from smaller to bigger fruit type as well as chemical contents of both the fruit types with bigger fruit type recorded higher content of acidity (3.32 %), ascorbic acid (58.38 mg/100 g), reducing sugar (4.44 %), total sugar (8.75 %), pectin (2.00 %), moisture (in fruit, 61.84 % and seed, 33.33 %) as compared to smaller fruit types. Fruit is eaten fresh and is also used for preparation of juice, squash, jam, RTS and wine.

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***Myrica esculenta* Buch.-Ham. ex D. Don (syn. *Myrica farquhariana* Wall.):** It belongs to Myricaceae family and this species is quite common in the Hills of Khasi, Jaintia, Lushai and Naga where it is cultivated (Kumar, 2002). Flowering takes place between first fortnight of October to second fortnight of December and fruits are available during from last week of March till last week of June. Average fruit weight (23.4 g), pulp (86.7%) and juice recovery (80.44%), TSS (9.0%), reducing sugar (2.44%), total sugar (6.67%), β carotene (3.86 mg/100 ml) and anthocyanin (13.84 (mg/100 ml) was observed. Fruits are consumed raw at all stages of its growth. Fruits are also used for preparation of pickle and attractive sparkling red colour refreshing drink.

***Baccaurea ramiflora* Lour. (syn. *Baccaurea sapida* Muell. Arg.):** This plant belongs to the Phyllanthaceae family. The species is found wild or semi- cultivated in the eastern India including the states of Meghalaya, Assam, Nagaland, Manipur, Mizoram, Tripura and Orissa and in Andaman and Nicobar Islands. Tree is evergreen up to 5 m height, with long branches from near the ground, particularly when the stem is laden with fruits (Sundriyal and Sundriyal, 2003). Fruit is yellow, velvety, 2-3 cm diameter, with leathery pericarp. Sometime, the yellowish ripe fruits turn into ivory to pinkish-buff or bright red. Pulp is aril with whitish and occasionally deep pink near seeds. Taste varies from acid to sweet in taste. Biochemical analysis of fruits revealed that TSS was 8.2-14.1 %, acidity 1.93 %, reducing sugar 5.10 % and total sugar 13.69 % besides, fruits are

also rich in protein and iron. Arils of ripened fruits are eaten and very delicious with high market preferences among the tribal population. Fruits are mainly used for preparation of squash, RTS, wine and jam (Patel *et al.*, 2008).

***Pyrus pashia* Hamilton ex D. Don (syn. *Malus pashia* Wenzig):** This wild Himalayan pear belongs to Rosaceae family. Tree is deciduous, medium size and white coloured flowers appear during February-March. Fruits are depressed at the proximal end, globose in shape and dark brown in colour when ripe. Physical parameters of fruit has a wide variation with weight varies between 6.57-44.25 gm, length 1.85-4.50 cm and diameter 2.21-5.13 cm. Fruits has TSS 31 %, total sugars 6.85 %, reducing sugars 6.79 %, acidity 0.97 %, moisture 62 %, tannins 0.42 %, vit. C 1.22 mg g⁻¹ pulp, pectin 0.4 %, ash 0.99 %, protein 3.68 %, phosphorous 0.026 %, magnesium 0.027 %, potassium 0.475 %, calcium 0.061 % and iron 0.006 %. This fruit is consumed raw by tribal population and is like for its grittiness and sweetness.

***Calamus meghalayensis* (Becc.) A.J. Hend. (syn. *Calamus floribundus* var. *depauperatus* Becc.):** The plant belongs to the Arecaceae family and believed to have originated in Khasi Hills of the northeastern India (Henderson and Henderson, 2007). It is locally known as Sohnil in Garo and Sohthri in Khasi and Pnar. Tree grows up to 2 m in height and bear fruits in bunches during February-April. Fruits are globose, varies from 1.5 to 3.0 cm in length and 1.0-2.0 cm width with light yellow peel

and white coloured aril (Rymbai *et al.*, 2016). Aril is very juicy, slightly acidic but very delicious and relished by the tribal population. Apart from the fruits, leaves are used for roof thatch making while the canes for domestic crafts.

***Docynia indica* (Wall.) Decne. (syn. *Docynia hookeriana* Decne.; *Malus docynioides* Schneid.):**

It is commonly known as Indian crab apple and belongs to the family Rosaceae. The species naturally occurs in forest areas of North Eastern India, up to an altitude of 900 to 1900 m a.s.l. This deciduous tree attains a height of up to 9-12 m. Flowers appears either solitary or arranged in fascicles of 2-3 during March to April. Fruits are pear or round shaped and greenish or yellowish colour with red tinged pale green colour when ripe which mature during August to November. The taste of the fruit ranged from medium sweetness to acidic and astringency varies with genotypes. Fruit is consumed fresh with salt or mixed with other fruits such as pumello, lemon or orange, boiled with sugar, sundried and consumed. Fruit is also sliced and sundried which can be stored for months and consumed during off-season. Pickles and jelly are also prepared from this fruit.

***Rhus chinensis* Mill. (syn. *R. semialata* Murr.; *R. javanica* L.; *Brucea javanica* (L.) Merrill):** It belongs to Anacardiaceae family is widely distributed in Khasi and Jaintia Hills of Meghalaya at an altitude ranging from 600 to 2400 m a.s.l. Whitish or pale green flower having long hairy pedicle appears during July-September. Fruit is a red

fleshy drupe, occurring in cluster of galls with red glandular hairs on the fruit wall. Fruit is reported to be rich in several antioxidants such as tannin, gallic acid and minerals like potassium acid salts, traceable amount of aluminium, calcium, magnesium and iron, acid salts of malic, tartaric and citric acids (Krisnamurthi, 2003; Khare, 2007). Fleshy drupe fruits are salty with sharp acidic taste and are consumed as whole when ripe. Fruits are sundried, powdered and stored in bottle by indigenous people for future use. Traditionally, fruits as a whole or powdered are used for treatment of diarrhoea, dysentery, ingestion, cough, wound bleeding, ulcerous dermatitis and toxic skin swelling (Dharmananda, 2003).



Elaeagnus latifolia L.



Padus napaulensis



Myrica esculenta



Baccarea ramiflora



Pyrus pashia



Calamus meghalayensis



Docynia indica



Rhus chinensis



Myrica farquhariana

***Myrica farquhariana* (Soh-phie-nam):** It is a moderate sized and ever green tree, which belongs to family Myricaceae. It is quite common in Sibsagar (Dikho valley), Naga hills, Khasi hills and Jaintia hills. The leaves are lanceolate, ovate nearly entire or serrate, male spikes sometimes with male flowers at

the top. Fruits are about 2.5 cm ellipsoidal or ovoid reddish or cheese colour at ripening. The ripe fruits are edible and used for making refreshing drink. The bark is used externally as stimulant for rheumatism and in the preparation of yellow dye (Patel *et al.*, 2005).

Conclusion

It may be concluded that domestication and promotion of the under-utilized fruit crops for commercial cultivation will not only serve as alternative source of nutrients but will also bring substantial income generation to the poor farmers of the remote areas of the region.

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Amaranthus: A Sustainable Solution for Global Nutrition

Archana Brar, Sunil Kumar and Anubhuti

Amaranthus, commonly known as amaranth, is a genus of plants in the family Amaranthaceae, which includes around 60 species. The plants are native to the Americas, but they can be found in various parts of the world today. Amaranthus species are known for their nutritious seeds and leaves, both of which have been cultivated for centuries for food. Amaranth grains are considered a pseudocereal, meaning they are used similarly to grains but do not come from grasses. These tiny, protein-rich seeds are gluten-free and high in essential nutrients like fiber, vitamins, and minerals, making them a popular food choice for those with dietary restrictions. Apart from its nutritional value, amaranth has also been appreciated for its ornamental uses, with some species, like *Amaranthus cruentus* and *Amaranthus hypochondriacus*, known for their striking, colorful flowers. Amaranth plants are often easy to grow and are used for various purposes, including in traditional medicine, as fodder, and in some cases, for their vibrant dye. Overall, amaranth is a versatile plant that offers both nutritional and aesthetic benefits.

In India, Amaranth is called Rajgira (royal grain) or Ramdana (grain given by Lord Ram), for its amazing utility and health benefits. In English, it is known as Kingseed or Amaranth (derived from a word which means 'never ending' in Sanskrit). It is also called as “golden grain of the gods” because of

its high nutritional value and its importance in their religious ceremonies. There are many reasons why amaranth is considered to be a superfood. It is a complete protein, meaning that it contains all nine essential amino acids that the human body cannot produce on its own. It is also a good source of dietary fiber, magnesium, iron, and calcium. Here are some of the health benefits of amaranth flour:

High in protein: Amaranth flour is a complete protein, meaning that it contains all nine essential amino acids that the human body cannot produce on its own. This makes it a good choice for vegetarians and vegans who are looking for a plant-based source of protein.

Good source of fiber: Amaranth flour is a good source of dietary fiber, which can help to keep you feeling full and satisfied after eating. Fiber also helps to regulate digestion and can help to lower cholesterol levels.

High in minerals: Amaranth flour is a good source of magnesium, iron, and calcium. Magnesium is important for energy production, muscle function, and bone health. Iron is essential for transporting oxygen throughout the body, and calcium is important for strong bones and teeth.

Low glycemic index: Amaranth flour has a low glycemic index, which means that it does not cause a sharp spike in blood sugar levels after eating.

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This makes it a good choice for people with diabetes or those who are looking to manage their blood sugar levels.

There are a few reasons why amaranth flour is known as the “god’s grain.” First, it was once considered to be a sacred food by many cultures, including the Aztecs, Mayans, and Incas. These cultures believed that amaranth was a gift from the gods, and they used it in religious ceremonies and offerings. Second, amaranth flour is a very nutritious food. It is a complete protein, and it is a good source of dietary fiber, magnesium, iron, and calcium. These nutrients are essential for good health, and they are often lacking in the modern diet. In addition to its nutritional benefits, amaranth is also a versatile grain that can be used in a variety of dishes. It can be ground into flour and used to make breads, tortillas, and other baked goods. It can also be popped like popcorn, or cooked and eaten as a cereal.

The genus *Amaranthus* consists of around 60 species of flowering plants, belonging to the *Amaranthaceae* family. These species are widely distributed across the globe, particularly in the Americas, and they are often recognized for their vibrant, colourful flowers and edible seeds. Some well-known species within the genus include:

***Amaranthus cruentus*:** Commonly referred to as “red amaranth” or “bloody amaranth.” It is cultivated for its edible leaves and seeds, often used in cooking in many cultures.

***Amaranthus retroflexus*:** Also known as “redroot pigweed” or simply “pigweed.” It’s often found as a

weed, but its young leaves are also edible and have been used in various culinary traditions.

***Amaranthus caudatus*:** Known as “love-lies-bleeding” due to its drooping, tassel-like flower clusters. It’s often grown for ornamental purposes and also for its edible seeds.

***Amaranthus hypochondriacus*:** This species is commonly referred to as “prickly amaranth” or “tassel flower.” It is used both as an ornamental plant and for its seeds.



Figure: Leafy Amaranthus and it’s seeds

Amaranthus is a fast-growing, drought-tolerant and highly nutritious crop that belongs to the *Amaranthaceae* family. The production technology of amaranthus involves several key steps, from seed preparation to post-harvest management. The cultivation practices of amaranthus are discussed below:

Variety Selection

Leafy Amaranthus: Varieties like *Amaranthus tricolor*, *Amaranthus gangeticus*, and *Amaranthus dubius* are grown primarily for their leaves. These leaves are consumed as vegetables.

Grain Amaranthus: Varieties like *Amaranthus*

cruentus, *Amaranthus hypochondriacus* and *Amaranthus caudatus* are grown for their seeds, which are highly nutritious.

Amaranthus grows best in well-drained, sandy loam to loamy soils with a pH between 6.0 and 7.5. Soils rich in organic matter enhance growth. It thrives in warm temperatures between 25°C and 35°C. It is drought-tolerant and can survive in areas with low rainfall, but adequate moisture improves yields. Ploughing and Harrowing: Prepare the land by ploughing to a fine tilth. Harrowing is important to break up clods and ensure a smooth seedbed. Before sowing, apply farmyard manure or compost (10-15 t ha⁻¹). A balanced fertilizer with NPK (nitrogen, phosphorus, potassium) in a ratio of 2:1:2 can be applied based on soil tests. Amaranthus can be sown during the warm seasons, ideally after the last frost. In tropical climates, it can be grown year-round. Direct seeding is commonly used. Seeds are sown at a depth of 1-2 cm. For leafy amaranthus, plant seeds in rows, 20-30 cm apart, with about 10-15 cm between plant. For leafy amaranthus, 3-5 kg of seed ha⁻¹ is used, while for grain production, 4-6 kg ha⁻¹ is typical. Row spacing of 30 cm and plant spacing of 15 cm is recommended for optimal growth. Amaranthus is drought-tolerant, but it requires adequate moisture during the germination and early growth stages. Regular irrigation is necessary during dry spells to prevent stunted growth. Over-irrigation can lead to root rot and other diseases, so proper drainage is essential. Weeding should be done early to avoid competition for nutri-

ents and water. Mechanical weeding or hand weeding can be employed. Thinning is essential to allow proper plant development. Mulching with organic matter can reduce weed growth, conserve moisture, and maintain soil temperature. Apply balanced NPK fertilizers before sowing. For leafy varieties, nitrogen can be applied after the first weeding to encourage leaf growth. For grain varieties, top-dressing with nitrogen at 30-40 days after sowing helps improve grain yield. If using organic fertilizers, compost, and vermicompost can be incorporated before sowing. Common pests affecting amaranthus include aphids, leafhoppers, and the red flower weevil. Use appropriate insecticides or natural predators to control pests. Leaf spot, downy mildew, and powdery mildew are common diseases. Proper crop rotation and maintaining proper spacing help reduce the incidence of diseases. Encourage natural pest predators, use biopesticides, and practice crop rotation. For leafy varieties, harvest begins when the plants are about 4-6 weeks old, depending on the growth stage. Young leaves are harvested by hand or with scissors. These can be harvested several times, as the plant will continue to produce new leaves. For grain production, harvest occurs when the seeds are mature, typically 3-4 months after sowing. The seed heads will turn dry and brown. The plants can be cut when 80-90% of the seeds have ripened. After harvesting the leaves, they should be cleaned and packaged immediately. They can be stored in cool, shaded places, or refrigerated to extend shelf life.

The seeds are separated from the seed head through threshing. The seeds should be cleaned and dried before storage. They should be stored in airtight containers in a cool, dry place to prevent moisture absorption and pest infestation. Amaranth seeds can be stored for long periods, but they should be kept in airtight containers to avoid insect infestation. For longer shelf life, storing at low humidity and temperature is recommended. Amaranth can be processed into flour, popped grains, or used in making nutritional snacks.

Conclusion

Amaranth has a strong market demand due to its high protein content, including essential amino acids like lysine. The market for amaranth seeds is expanding in both domestic and international markets. Leafy amaranthus is a popular vegetable in many regions and can be sold fresh in local markets or used in processed products. Amaranth grain is used in various food products, including cereals, snacks, and as a gluten-free alternative in baking.

Women in Agriculture

Priya Satwadhar and Devshree Panchbhai

Introduction

Women are an essential element of the agricultural labor and the Indian economy. When it comes to farming in India, it's the women who do the heavy lifting. Women, who make up the vast majority of farm workers, have consistently shown high standards of both physical and intellectual productivity. Her education would transform rural India via a variety of well-planned initiatives. Women's participation and leadership in agriculture varies widely among nations. Women in Asia are responsible for almost half of the food supply. In most cases, the proportion of women working in agriculture increases in direct proportion to the family's economic status. Despite playing an essential role in agricultural progress and related industries, women have almost no access to agricultural information, services, or production assets and very little say over their own incomes. There are a disproportionate number of women working in agriculture. In rural areas of India, women make up the vast majority of the labor force (84%). Seventy-three percent of these women are employed in agriculture, with the vast majority (96%) working in rural regions.

Women are integral members of farming communities world-wide and they play a wide range of responsibilities (including decision-making) and have varying degrees of influence over resources and earning

Women in agriculture: Women make essential contributions to agriculture and rural economic activities in all developing country regions. Their roles vary considerably among and within regions and are changing rapidly in many parts of the world where economic and social forces are transforming the agriculture sector. The emergence of contract farming and modern supply chains for high-value agricultural products, for example, present different opportunities and challenges for women than they do for men. These differences derive from the different roles and responsibilities of women and the constraints that they face. Women work in agriculture as farmers on their own account, as unpaid workers on family farms and as paid or unpaid laborers on other farms and agricultural enterprises. They are involved in both crop and livestock production at subsistence and commercial levels. They produce food and cash crops and manage mixed agricultural operations often involving crops, livestock and fish farming.

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All of these women are considered part of the agricultural labor force. The Southern Asian average is dominated by India, where the share of women in the agricultural labor force has remained steady at just over 30 percent. This masks changes in other countries where the female share of the agricultural labor force appears to have increased dramatically, such as Pakistan where it has almost tripled since 1980, to 30 percent, and Bangladesh where women now exceed 50 percent of the agricultural labor force.

Challenges faced by women in agriculture

Access to finance: Poor access to financing is another major setback faced by women in agriculture. Credit is an extremely useful resource to farmers due to the fact that their production activities are most often seasonal in nature and a considerable lag occurs between the time they incur costs and the time that they are able to generate income from their produce.

Some of the most relevant ones include;

- ✓ Limited education and mobility
- ✓ Socio-cultural impediments
- ✓ Lack of collateral requirements
- ✓ Irregularity of employment

Gender division of labour in agriculture: Gender division of labour in agriculture is a common practice that has often been viewed by several people as a limiting factor for most women. The major reason for this categorization is that women are responsible for feeding the family and thus prefer to grow subsistence crops for household consumption. On the other hand, men in agriculture

are breadwinners of their homes and as such are expected to grow cash and export crops that will generate higher income for the family.

Access to Education: Education is a key factor in improving women's productivity and economic status in agriculture. However, many women in rural areas do not have access to quality education due to cultural, social, and economic barriers. Providing education and training in agricultural practices, financial management, and entrepreneurship can help women increase their productivity, income, and leadership skills.

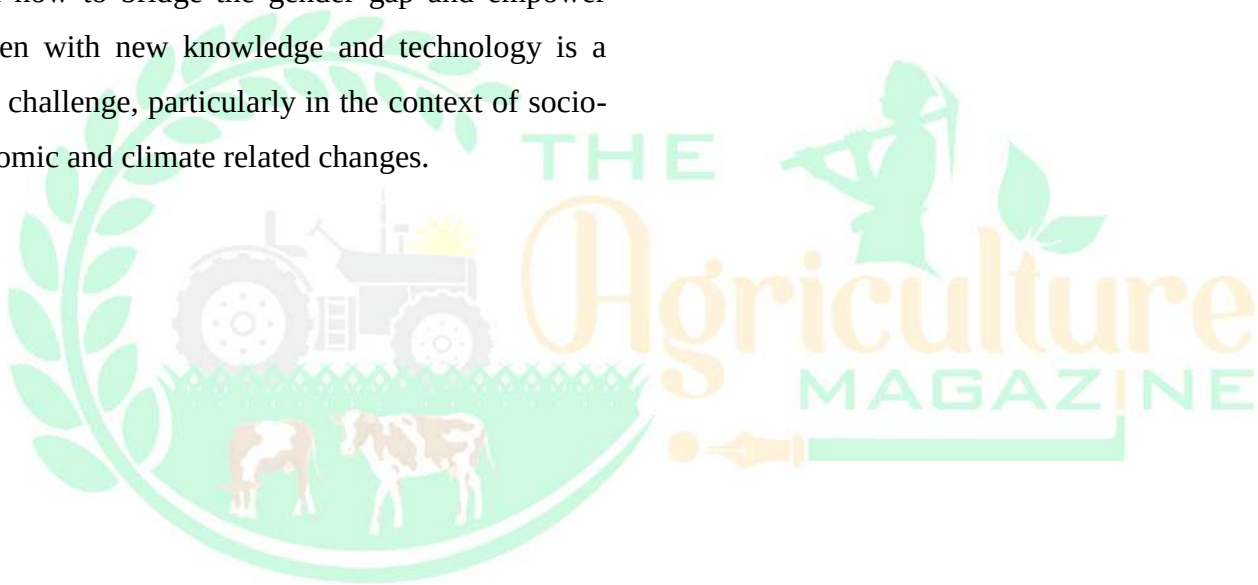
Land Ownership: Land is a critical asset for agricultural production, yet women often face significant barriers to land ownership and control. In many countries, cultural and legal norms prioritize male inheritance and ownership, leaving women without access to land. Addressing these barriers and providing women with secure land tenure can improve their productivity, income, and decision-making power in agricultural production.



Conclusion

Women have been contributing enormously to agricultural growth and development through their involvement in crop production, horticulture, animal husbandry, fisheries, natural resource management etc. Though the proportion of women workers in agriculture has declined, yet they constitute a signif-

ificant workforce in agriculture. Globally, they constitute large percent of economically active population in agriculture. Women's contribution varies across regions, socio-cultural and agro-production systems. On the other hand, the persisting gender gap in access to and control of resources remains an important concern which has not only kept women in a vicious circle of low productivity but also has thrown up questions about inclusive and sustainable growth of the sector. The need of the hour is on how to bridge the gender gap and empower women with new knowledge and technology is a great challenge, particularly in the context of socio-economic and climate related changes.



AI in Greenhouse: Revolutionizing Climate Control for Maximum Crop Productivity

Abhilash U. Bagunavar, Iranna Biradar and Vaibhavi S. Patil

Abstract

Artificial Intelligence (AI) is reshaping the future of greenhouse agriculture by providing precise control over environmental variables that govern plant growth. With rising challenges from climate change, resource scarcity, and the need for sustainable intensification, AI-enabled greenhouses offer a promising solution for maximizing crop productivity. This article explores how AI technologies are revolutionizing greenhouse management regulating temperature, humidity, CO₂, light, and irrigation to ensure ideal growth conditions throughout the crop cycle. Case studies, practical benefits, and real-time applications are discussed, making the case for AI-powered cultivation as a sustainable agricultural strategy.

Introduction

Greenhouses offer a controlled environment for year-round cultivation of high-value crops such as tomatoes, bell peppers, lettuce, and flowers. However, maintaining optimal conditions for plant growth manually can be labour-intensive and prone to inefficiencies. Enter Artificial Intelligence (AI) a transformative technology that integrates data from multiple sources to autonomously monitor and regulate critical environmental parameters. Modern greenhouses now employ AI-powered systems that analyze sensor data, weather forecasts, and crop requirements to dynamically adjust temperature, humidity, lighting, and irrigation. The result is improved crop health, higher yields, and reduced resource waste.

Key Environmental Factors Managed by AI in Greenhouses

Parameter	AI Functionality	Benefit to Crops
Temperature	Predictive control using sensors and external forecasts	Avoids heat stress or cold injury
Humidity	Real-time adjustments via smart ventilation	Prevents fungal diseases; improves uptake
CO ₂ Concentration	Automated enrichment systems based on crop stage	Boosts photosynthesis and biomass
Light Intensity	AI-controlled LED systems with day-length adaptation	Ensures optimal photoperiod and growth
Irrigation	AI-drip and fog systems linked with soil moisture data	Reduces water use, avoids root stress

AI Technologies Used in Greenhouses

Sensors and IoT Devices: Monitor temperature, light, soil moisture, pH, CO₂ levels, and plant health in real time.

Machine Learning Algorithms: Learn patterns in

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plant growth, optimize environmental parameters, and predict potential problems (e.g., disease outbreaks).

Computer Vision Systems: Use cameras to analyze leaf color, size, and canopy density, allowing AI to make nutrient or light adjustments accordingly.

Cloud-Based Dashboards: Provide farmers with remote access to all greenhouse data and controls from smartphones or laptops.

Autonomous Systems: Robots and drones can be programmed to perform pruning, harvesting, and pest control based on AI insights.

Benefits of AI-Driven Greenhouse Management

Increased Crop Yields: AI maintains ideal growth conditions, enabling consistent and enhanced productivity.

Reduced Input Costs: Optimized use of water, nutrients, and energy leads to significant savings.

Improved Quality: Better climate control results in uniform growth, improved taste, color, and nutritional content.

Labor Efficiency: Automation reduces manual workload and allows for remote management.

Early Problem Detection: AI can detect early signs of pest infestations or plant diseases, preventing crop loss.

Crop Examples Benefiting from AI-Greenhouses

Tomato: AI regulates light and humidity to reduce blossom-end rot and improve fruit size.

Lettuce: Smart irrigation and temperature control lead to uniform leaf development and faster cycles.

Strawberry: Controlled CO₂ and precise fogging

systems enhance sugar content and color.

Capsicum: AI balances light intensity and temperature to improve yield per square meter.

Challenges and Future Prospects

Despite its potential, AI-based greenhouse systems come with challenges:

High Initial Cost: Advanced AI and sensor setups require substantial investment.

Skill Requirement: Farmers need training to interpret AI outputs and maintain systems.

Data Dependency: Systems are only as good as the data they receive; sensor failure or bad connectivity can reduce effectiveness.

Future Outlook

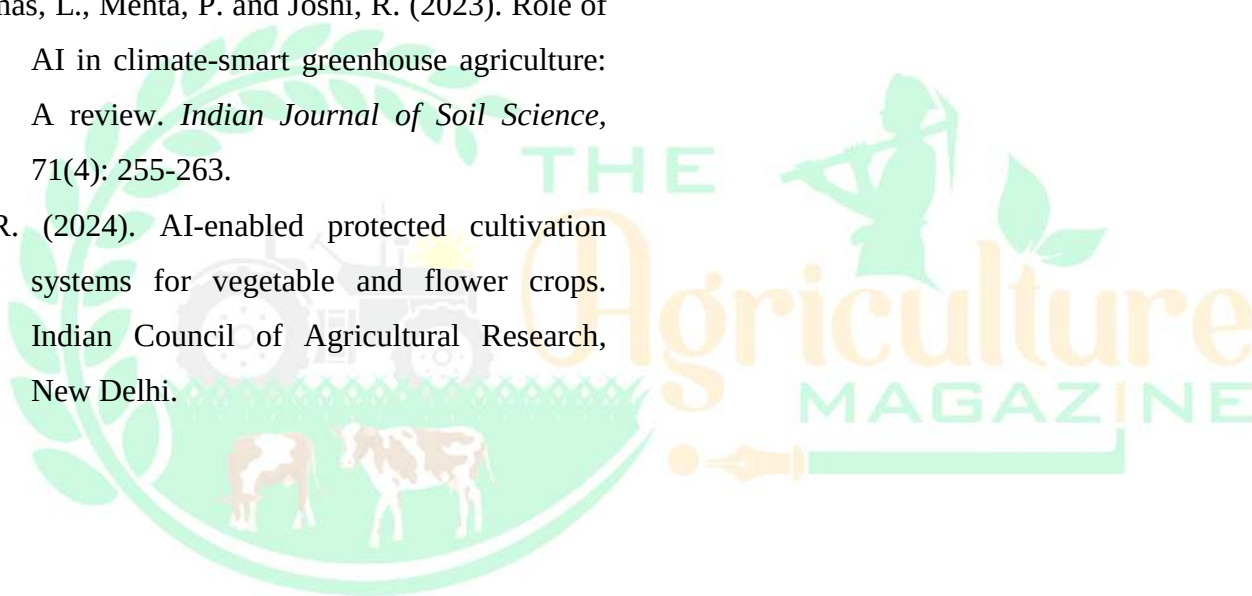
- ✓ Integration of blockchain for traceability.
- ✓ Use of AI with drones for in-canopy climate assessment.
- ✓ Enhanced predictive modeling using real-time weather data and crop genomics.
- ✓ Scalable AI kits for smallholder greenhouses to democratize smart farming.

Conclusion

AI is redefining how greenhouses are managed, transforming them from passive structures into intelligent, self-regulating crop production units. By leveraging AI's ability to process and act on vast data streams, farmers can fine-tune every aspect of the plant environment resulting in higher yields, better quality, and sustainable practices. As this technology becomes more accessible, the dream of precision-controlled, resource-efficient farming is turning into reality across the globe.

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AI in Action: Smart Irrigation and Microclimate Control for Plantation Crops

Abhilash U. Bagunavar, Dhananjay Hirepatta and Vinay Kumar K. N.

Abstract

The integration of artificial intelligence (AI) in plantation agriculture is redefining how water and environmental conditions are managed. AI-enabled irrigation systems and microclimate monitoring tools are offering timely, precise, and efficient control over growing conditions, thereby improving yield quality, reducing water wastage, and promoting sustainability. This article explores the practical applications of AI in irrigation and microclimate management for plantation crops like tea, coffee, coconut, and rubber where small changes in environment can have large impacts on productivity and profitability.

Introduction

Plantation crops are sensitive to micro-climatic factors such as humidity, temperature, soil moisture, and solar radiation. Traditional irrigation systems often follow fixed schedules, lacking responsiveness to real-time changes in weather or soil conditions. This can result in water wastage, nutrient leaching, or stress to crops during dry periods. Similarly, subtle fluctuations in temperature and humidity can affect the flowering, fruiting, and disease susceptibility of plantation crops. Artificial Intelligence (AI), when combined with sensor technology and weather data, enables real-time decision-making for irrigation and microclimate adjustments. From managing drip irrigation based on evapotranspiration rates to activating foggers or ventilation systems inside greenhouses, AI is making

plantation agriculture smarter, more efficient, and climate-resilient.

Applications of AI in Smart Irrigation

AI-based irrigation systems work on real-time data received from:

- ✓ Soil moisture sensors
- ✓ Weather forecasts
- ✓ Crop evapotranspiration models
- ✓ Canopy temperature sensors

These systems analyze the inputs and generate optimal irrigation schedules tailored to plant needs. In plantation crops where over- or under-watering can severely affect yield and quality, AI ensures precision. For example, in coffee plantations, AI systems can reduce water usage by up to 35% while maintaining bean size and quality. Similarly, in coconut and arecanut farming, AI can

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Table 1: Benefits of AI-Enabled Systems in Plantation Crop Management

Crop	AI Application	Result	Water Savings
Coffee	AI-based drip irrigation	Improved bean uniformity and flowering	30-35%
Tea	Microclimate control (humidity)	Increased leaf tenderness, reduced blister blight	25-30%
Coconut	Smart irrigation + weather AI	Higher nut retention, improved growth during summer	20-25%
Rubber	AI-assisted irrigation scheduling	Enhanced latex yield during dry spells	15-20%

optimize irrigation during peak summer, ensuring healthy nut development.

Microclimate Monitoring and Management

Microclimate management refers to controlling parameters like:

- ✓ Air temperature
- ✓ Relative humidity
- ✓ Light intensity
- ✓ Wind speed

In crops like tea, where leaf tenderness and flavor are microclimate-sensitive, AI-controlled systems regulate shade, misting, and ventilation automatically. AI also helps predict pest and disease outbreaks by correlating weather conditions with historical crop performance.

AI Tools and Technologies in Practice

AI-Driven Soil Moisture Systems: These systems use machine learning to model water retention and drainage patterns in different soil layers, offering precision irrigation in sloped or variable soils often found in plantations.

Digital Twin Models for Climate Prediction: AI creates real-time models of the field environment, simulating weather and plant interactions to guide microclimate interventions like fogging, ventilation, or heating.

Integration with IoT Devices: Internet of Things (IoT) devices like smart valves, remote pumps, and solar-powered sensors connect with AI to automate

actions without human intervention.

AI in Pest and Disease Forecasting: By monitoring humidity, leaf wetness duration, and temperature, AI systems can alert farmers to high-risk periods for diseases like coffee rust or tea blister blight, allowing timely action.

Challenges and Considerations

While the benefits are clear, there are challenges:

Cost of Installation: AI systems require initial investment in sensors, connectivity, and software.

Technical Knowledge: Farmers need training to operate and interpret AI systems.

Connectivity: Remote plantation areas may face internet limitations.

However, government schemes and private agritech firms are increasingly making these solutions accessible through pay-per-use models, mobile apps, and solar-powered networks.

Conclusion

AI is no longer futuristic in agriculture it is a present-day reality with tangible benefits. In plantation crops, where microclimate and water use directly influence yield and quality, AI offers a critical edge. By enabling real-time, data-driven decisions, AI helps conserve water, improve crop resilience, and enhance productivity. As technology becomes more affordable and accessible, its role in shaping the future of plantation farming will only grow stronger.

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Smart Farming with Drones: A New Age of Precision Agriculture

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Introduction

Agriculture in India is witnessing a transformation like never before. With challenges such as climate change, labor shortages, and increasing input costs, farmers are now turning to technology-driven solutions for better efficiency and profitability. Among these, drones also known as unmanned aerial vehicles (UAVs) have emerged as a game-changer in modern farming. Drones are no longer limited to aerial photography or defense. They're now flying across Indian farms to monitor crops, spray fertilizers, detect diseases, and gather real-time data. This evolution marks the rise of smart farming, where precision, sustainability, and productivity go hand in hand.

What is Smart Farming with Drones?

Smart farming involves the use of advanced technologies such as artificial intelligence (AI), GPS, sensors, and drones to optimize farm operations. Drones, specifically, offer a bird's-eye view of farmland, helping farmers assess plant health, plan input application, and manage resources more effectively.

Drones in agriculture can:

- ✓ Capture high-resolution aerial images
- ✓ Monitor crop health and growth patterns
- ✓ Spray fertilizers and pesticides uniformly
- ✓ Assess soil conditions

Predict yields and detect early signs of stress

With this data, farmers can make informed decisions, reduce wastage and improve crop productivity.

Scientific Applications of Drones in Agriculture

Crop Health Monitoring (NDVI Analysis): Drones equipped with multispectral cameras can measure plant health using Normalized Difference Vegetation Index (NDVI), which identifies stressed, diseased, or nutrient-deficient plants. Healthy vegetation shows high NDVI values (0.6-0.9), while unhealthy or sparse vegetation scores lower.

Precision Spraying: Drones can spray agrochemicals with pinpoint accuracy, minimizing input costs and human exposure to harmful chemicals.

- ✓ Reduces chemical use by 20-30%
- ✓ Saves up to 90% water compared to conventional methods
- ✓ Covers 1 acre in 7-10 minutes

Soil and Terrain Mapping: By analyzing elevation and moisture patterns, drones help in planning irrigation and preventing waterlogging. This supports site-specific nutrient management (SSNM).

Plant Counting and Yield Estimation: AI-integrated drones can count plants, analyze flowering stages, and estimate potential yield crucial for insurance, market planning, and input budgeting.

Benefits of Using Drones on Farms

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Advantage	Outcome
Faster input application	Saves time and reduces labor dependency
Uniform spraying	Reduces overuse of fertilizers/pesticides
Early detection of issues	Prevents crop losses and supports timely action
Resource optimization	Saves water, chemicals, and fuel
Data-driven farming	Enables better planning and profitability

India's Leading Agri-Drone Startups

Several Indian startups are using drone technology to solve real farm-level problems:

Garuda Aerospace (Chennai): Offers drone-based spraying and crop surveillance services.

Marut Drones (Hyderabad): Specializes in precision agriculture and disease mapping.

IoTechWorld Avigation (Gurugram): One of India's first DGCA-approved agri-drone manufacturers.

Many of these companies follow a Drone-as-a-Service (DaaS) model, making the technology affordable for small and marginal farmers without the need to purchase drones themselves.

Government Support for Drone Technology in Agriculture

The Indian government is actively promoting drones in farming through various schemes and policy changes:

Drone Shakti (Union Budget 2022): Encourages startup-led drone services across sectors.

Subsidies under SMAM (Sub-Mission on Agricultural Mechanization): Custom Hiring Centres (CHCs) and FPOs can receive up to ₹10 lakh for drone procurement.

DGCA-Approved Training Centers: To build a

certified pool of drone pilots and operators.

Involvement of Krishi Vigyan Kendras (KVKs):

For on-field demonstrations and farmer awareness programs.

These initiatives are making drone services more accessible, especially in rural and remote areas.

Challenges in Drone Adoption

While the potential is enormous, some challenges remain:

- ✓ High initial cost of drones, though DaaS helps offset this
- ✓ Limited awareness and training among rural farmers
- ✓ Regulatory hurdles for drone licensing and airspace clearance
- ✓ Short battery life and limited payload for large farms

To address these issues, there's a growing need for:

- ✓ More pilot training programs
- ✓ Crop-specific drone solutions
- ✓ Integration with mobile apps and AI for real-time advisory

Conclusion

Drones are more than just flying machines, they are tools of empowerment for Indian farmers. By making agriculture faster, smarter, and more efficient, drone technology is leading the way toward precision farming. As startups, government bodies, and research institutions join forces, the dream of high-tech, sustainable agriculture is becoming a reality. With continued innovation, affordability, and awareness, smart farming with drones will play a key

role in building a future-ready Indian agriculture, one that feeds more, wastes less, and nurtures the planet.

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Biofortification: Engineering Crops for Better Nutrition

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Abstract

Biofortification is a growing movement in agriculture aimed at addressing one of the world's most persistent problems: micronutrient malnutrition. Unlike traditional fortification, which adds nutrients to food after harvest, biofortification builds nutrition directly into the crops themselves. By using natural breeding methods or biotechnology, scientists are helping develop crops that offer more iron, zinc, and vitamin A right from the soil to the plate. For farmers, this means growing crops that not only feed but also nourish. For consumers, it means better health from the very first bite.

The Hidden Side of Hunger

We often talk about hunger as not having enough food, but there's another kind that's easy to overlook: hidden hunger. It happens when diets lack essential vitamins and minerals. People may eat enough to feel full, but their bodies still miss key nutrients. In India, this form of hunger touches millions of lives. Many children struggle with stunted growth, women suffer from anemia, and entire communities face weakened immunity due to vitamin and mineral deficiencies. While supplements and fortified foods help, they don't always reach rural areas consistently. Biofortification offers a different kind of solution. It works at the root of the problem, literally, by improving the nutritional value of crops as they grow.

What is Biofortification, Really?

At its core, biofortification means growing crops that are naturally richer in nutrients. This can

be done through:

- ✓ Traditional plant breeding, where scientists cross varieties that naturally have higher nutrient levels.
- ✓ Modern biotechnology, which adds specific genes to increase nutrition (as seen in Golden Rice).
- ✓ Soil and fertilizer techniques that help plants absorb more minerals from the ground.

The Nutrients that Matter Most

Biofortification mostly focuses on nutrients people commonly lack:

Iron: To fight anemia and fatigue.

Zinc: To support growth and immune strength.

Vitamin A: To maintain good eyesight and prevent infections.

These nutrients are critical, especially for children and women, and yet often missing from diets in low-income and rural communities.

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Crops that Carry Better Nutrition

Iron-Rich Pearl Millet (Dhanashakti): This variety developed by ICRISAT contains almost double the iron compared to standard types. Farmers in Maharashtra and Rajasthan are already growing it with good results.

Zinc-Enriched Wheat: Wheat varieties like Zinc Shakti provide more zinc per meal. This is especially helpful in wheat-eating regions across northern India.

Provitamin A Maize: This maize contains beta-carotene, which turns into vitamin A in the body. It's already being used in parts of Africa and is under field testing in India.

Golden Rice: This rice has been genetically modified to produce beta-carotene in the grain. Although still pending full approval in India, it shows great promise for reducing vitamin A deficiency.

Iron & Zinc-Fortified Rice: Research teams at IRRI and Indian institutions are developing rice varieties with enhanced iron and zinc, aiming to help regions where rice is a dietary staple.

How Biofortified Crops help Farmers too

Biofortified crops aren't just healthier; they're also practical and profitable. They offer:

- ✓ High yields that match or exceed regular varieties.
- ✓ Better disease resistance, saving money on pesticides.
- ✓ No major change in farming practice, just a different seed with better traits.

- ✓ Potential for premium markets as awareness grows.

For many farmers, especially smallholders, these crops offer a chance to contribute to public health while improving their own incomes.

India's Growing Role in Biofortification

India is already at the forefront of this nutritional farming revolution. Organizations like ICAR, HarvestPlus, and State Agricultural Universities are leading efforts to develop and promote nutrient-rich seeds.

Some key developments include:

- ✓ Over 80 biofortified crop varieties released by ICAR, including rice, wheat, maize, mustard, and lentils.
- ✓ Krishi Vigyan Kendras (KVKs) conducting field demos and training sessions to spread awareness.
- ✓ National nutrition programs like Poshan Abhiyaan aligning with biofortification goals.
- ✓ Government inclusion of biofortified foods in midday meal schemes and PDS (ration) programs.

What's Still Holding it Back?

Despite its advantages, biofortification faces a few barriers:

- ✓ Low awareness among farmers and consumers.
- ✓ Limited seed availability in some regions.
- ✓ Slow adoption of GM-based crops like Golden Rice due to regulatory concerns.

To move forward, India needs stronger seed distribution, more farmer training and better communication about the health benefits of biofortified food.

A Future Where Food Heals

Imagine a future where children grow up healthy, free from anemia and poor growth, simply because the rice on their plate contains more iron. Where women find strength not through supplements, but through the zinc-rich wheat in their daily chapatis

That's the future biofortification is building. Quietly, scientifically, and sustainably. With every seed planted, we get a step closer to farms that not only feed the world but heal it too. The journey starts in the soil, with the right seed and it ends with better health on every plate.

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