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Innovative Business Models Emerging from Agri-Incubators

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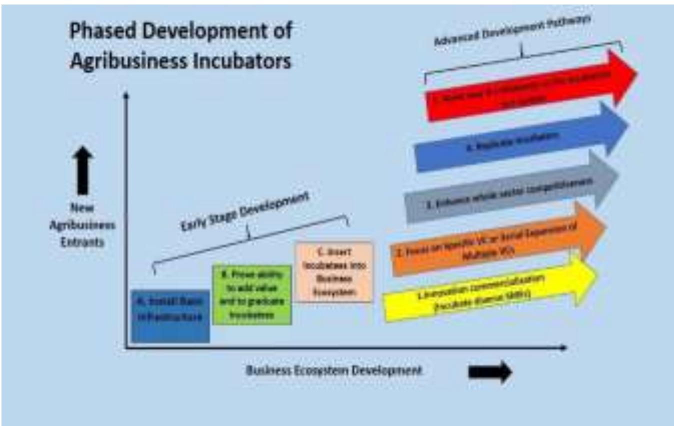
Agri-incubators are revolutionizing the agrifood sector by incubating startups that provide innovative, tech-based, and sustainable solutions. Agri-incubators facilitate various business models such as platform-based services, shared economy models, precision agriculture, agri-fintech, and waste-to-wealth businesses. Agri-incubators foster early-stage entrepreneurs through mentorship, funding, infrastructure, and policy support to tackle fundamental challenges such as productivity, climate resilience, and market access. Backed by national initiatives and international partnerships, they are creating an innovative agri-startup ecosystem that promotes rural growth, improves farmer earnings, and aligns with the aims of new-age, sustainable agriculture.

2. Introduction and Background

2.1 Introduction

The farming sector is going through a paradigm shift with the merger of innovation, entrepreneurship, and digital technologies. Conventional agriculture is being revolutionized by smart farming techniques, decision-making based on data, and new-age agritech solutions. In the midst of this change, agri-incubators are becoming key enablers for the development of agri-based startups and entrepreneurial ventures. Incubators serve as support systems to emerging agripreneurs through provision of access to mentorship, infrastructure, funds, market linkages, and advisory services. They play a particularly vital role in developing innovative business models that are not only economically sound but also environmentally sustainable and socially inclusive. Mittal *et.al.*2019.

By filling the interstice between research and grassroots action, agri-incubators enable entrepreneurs to address actual farming problems like low productivity, post-harvest losses, supply chain inefficiencies, and market disconnections. As emerging smart technologies like IoT, AI, blockchain, and drones are emerging, agri-incubators are promoting innovation along the value chain — from farm to fork.



Source: https://aesanetwork.org

2.2 What Are Agri-Incubators?

Agri-incubators are institutional hubs meant to nurture early-stage agri-businesses and allied sector businesses. Either hosted by agricultural universities,

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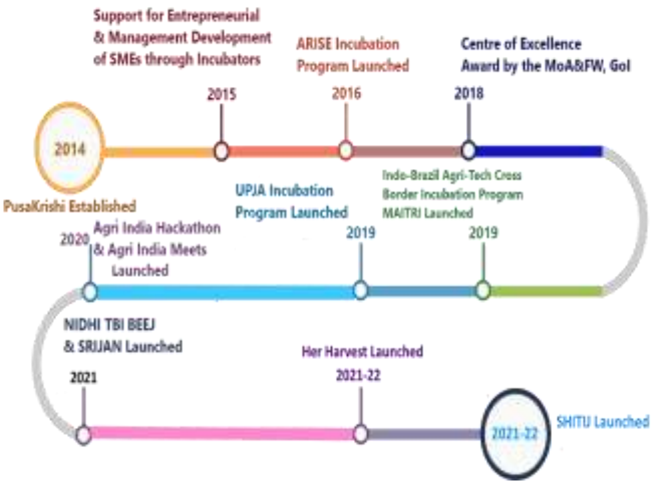
ICAR institutions, or private sector entities, or by public-private partnerships, these incubators serve as technology-based, service-based, or product-based agri-startups launchpads. Backed by national programs like RKVY-RAFTAAR, Agri-Business Incubation (ABI) Scheme, and Atal Innovation Mission, agri-incubators offer services ranging from business planning to prototype development, validation, market intelligence, IP registration, and facilitation of funding. These centers are at the forefront of building the rural innovation ecosystem and improving the role played by agriculture in the contemporary economy. Nath *et.al.* 2024.

3: Features and Services of Agri-Incubators

3.1 Major Services Offered by Agri-Incubators

Agri-incubators have a major role in developing agri-entrepreneurship by providing a broad array of technical, financial, and business support services. Agri-incubators also serve as innovation and commercialization catalysts by facilitating an environment for start-ups and innovators. Some of the most important services offered are:

- Business Mentorship and Advisory: Professional counseling on business planning, strategy, and operations from seasoned professionals, scientists, and industry experts.
- Seed Funding and Grants: Early-stage financing access, government grant access, and investor access to make ideas into viable businesses.
- Product Validation and Testing Support: Prototype testing facilities, laboratory analysis, and field demonstration facilities to develop technologies and products.
- Market Linkages and Branding Assistance: Brand building support, packaging development, pricing strategy development, and access to markets and buyers.
- Networking with Investors and Stakeholders: Pitches to venture capitalists, government institutions, buyers, and agri-tech partners.
- Legal and IP Support: Facilitating patent filing, licensing, and intellectual property protection to secure innovations.
- Pilot Field Trials and Farmer Feedback: Ground-truthing through field trials with farmers to gain feedback and refine solutions.



Source: https://pusakrishi.in

3.2 Target Audience

Agri-incubators serve a broad range of stakeholders in the agri-value chain, including:

- Early-stage agritech startups
- Individual rural innovators
- Farmer Producer Organizations (FPOs)
- Student entrepreneurs and potential agripreneurs
- Women and youth involved in agri-based enterprises

4. New Innovative Business Models

Agri-incubators are powering the next wave of business models that harmonize technology, inclusivity, and sustainability. Such novel methods are designed to boost productivity, eliminate inefficiencies, and grow farmer incomes by bridging the key gaps in agriculture and allied industries. Some of the most promising classes of models from incubated start-ups are given below.

4.1 Platform-Based Models

Digital platforms are now strong means of bringing together various parties in the value chain of agriculture. They are reshaping service provision and access to markets:

Input-as-a-Service (IaaS): Such models provide a digital platform for buying seeds, fertilizers, crop protection chemicals, and micronutrients, usually combined with advisory. Illustration: DeHaat, AgroStar

Farm-to-Fork Platforms: These platforms form a direct connection between farmers and consumers, restaurants, or retailers, thus eliminating middlemen and providing better returns to farmers. Example: Freshokartz, BigHaat

4.2 Shared Economy Models

Motivated by the shared economy idea, these models make the maximum use of costly resources:

Uberization of Farm Services: Startups offer tractors, drones, and harvesters on rent, making mechanization available to smallholder farmers. Example: EM3 Agri Services

Warehouse Sharing Models: Incubators promote models that allow for sharing of cold storage and warehouses, enabling farmers to minimize post-harvest losses and maintain quality.

4.3 Agri-Fintech and Credit Access Models

Technology-driven models are reshaping financial inclusion:

Startups are leveraging satellite data, IoT sensors, and AI to evaluate risk, offer crop insurance, and approve real-time loans, even in under-served rural India. Example: Samunnati, Jai Kisan

5. Deep-Tech and Climate-Smart Models

Agri-incubators are at the forefront of speeding up the use of cutting-edge technologies and green practices in farming. Startups funded via these incubation platforms are building deep-tech solutions that improve farm-level decision-making, minimize environmental imprints, and climate-proof agriculture. These new models are not merely transforming traditional farming techniques but also gearing the industry up for a more adaptive and technology-intensive future. Subash *et.al.* 2016.

5.1 Precision Agriculture Models

Precision agriculture is transforming farming through the use of Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), and remote sensing to provide site-specific and data-intensive recommendations. This helps improve input efficiency, increase yields, and reduce wastage of resources.

Incubated startups are providing:

Sensor-based advisory systems monitoring real-time parameters such as soil moisture, pH, temperature, and nutrient levels to enable farmers to make timely and accurate decisions.

Drone-based spraying and imaging services for pest and disease management, crop monitoring, and targeted input application, hence minimizing chemical use and labor dependency.

5.2 Climate Resilient Agri-Tech Models

With growing climate uncertainty, startups are creating models with a focus on sustainability and resilience:

- Drought-resistant crop varieties and micro-irrigation systems are being encouraged to provide water-use efficiency.
- Carbon farming practices, along with carbon credit platforms, are encouraging farmers to adopt climate-resilient approaches.

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- Hydroponic and vertical farming systems are being created to support high-density production in urban and resource-constrained regions, with reduced land and water requirements and year-round yield.

5.3 Circular Economy and Waste-to-Wealth Models

Agricultural waste is being repurposed by innovative startups into valuable commodities under the principles of a circular economy:

- Converting crop residues into biofuels, biochar, organic compost, and biodegradable packaging is becoming popular.
- Entrepreneurial models based on vermicomposting, organic input production, and eco-labeling are developing, earning sustainable livelihoods and lowering environmental pollution.

6. Institutional and Policy Support

The success of agri-incubators in India is premised upon a well-formulated institutional and policy framework. Government programs, academic partnership, private sector involvement, and global partnership are providing an enabling environment that allows agripreneurs to grow and upscale innovations.

6.1 National Programs Supporting Agri-Incubation

The Government of India has launched several flagship programs to promote agri-startups and business incubation. One such initiative is RKVY-RAFTAAR (Rashtriya Krishi Vikas Yojana – Remunerative Approaches for Agriculture and Allied Sector Rejuvenation), which supports incubators through funding, capacity building, and startup mentoring.

Prominent institutions like NAARM's a-IDEA, MANAGE's Centre for Agribusiness Incubation, and IARI's ZTM-BPD serve as nodal incubation centers for nurturing early-stage innovations.

Besides it, the country-level platforms such as Startup India, PM Formalization of Micro Food Enterprises (PMFME), and Atal Incubation Centres are giving support in terms of finances, infrastructure, and policies to agri-based entrepreneurs. Chaudhary *et.al.* 2024.

6.2 Academia and PPP Models

Academia is playing a pivotal role in technology transfer and commercialization of research. By incorporating startups into research framework, agricultural universities and ICAR institutes provide technical advice and validation support. At the same time, Public-Private Partnerships (PPPs) are filling gaps between market and research. Players such as Mahindra, TAFE, etc., are actively promoting incubation through mentorship, field testing, and co-development. CSR (Corporate Social Responsibility) initiatives are also increasingly supporting funds for innovation labs and rural business accelerators. Singh *et.al.* 2023.

6.3 International Collaborations

Agri-incubators are also gaining from international collaborations with bodies such as USAID, FAO, and GIZ, who are providing technical support, capacity building, and policy guidance. Joint ventures like Indo-Israel and Indo-Dutch incubators are bringing cutting-edge agri-tech solutions, especially in precision irrigation, protected cultivation, and climate-smart agriculture.

7. Challenges, Case Studies, and Way Forward

7.1 Challenges Confronted by Agri-Incubators

Despite becoming increasingly important, agri-incubators in India are confronted with a range of structural and operational problems. Limited digital infrastructure in rural areas is one of the main issues, which is deterring outreach and adoption of tech-enabled solutions.

Moreover, commercialization and scale-up support for incubated startups is still lacking. Most

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innovations are not able to survive the "valley of death" owing to limited access to markets and investment.

Low investor confidence in seed-stage agri-startups also exists, primarily caused by perceived risk and gestation periods. Besides that, regulatory hurdles, low awareness of intellectual property rights (IPR), and bureaucratic delays in the release of funds are hindrances to growth.

7.2 Success Stories and Case Studies

A number of startups have made it big out of agri-incubators, illustrating the life-changing potential of these networks:

- AgNext has created AI-powered platforms to analyze the quality of agricultural produce in real time.
- Stellapps employs IoT and data analytics to enhance dairy supply chain productivity and traceability.
- Ecozen provides solar-powered cold storage and pump systems, improving rural farm energy access.
- KrishiHub brings farmers directly in contact with restaurants and retailers, cutting out middlemen and guaranteeing improved prices.

7.3 Way Forward

Regional incubator networks must be increased and district-level incubation centers need to be set up to bolster the agri-startup ecosystem. There need to be focused efforts toward promoting gender-diverse and youth entrepreneurship, as well as agri-clinic and rural service center development. Finally, utilizing AI, blockchain, and IoT will make Indian agri-value chains transparent, efficient, and traceable.

8.Conclusion

Agri-incubators are establishing a new generation of technology-enabled, socially relevant, and resilient agri-business models. These start-ups are not only stimulating rural economies but also placing Indian agriculture on the global map. For sustainable growth, an interactive ecosystem of government, academia, private investors, and rural communities is required.

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Integrated Nutrient Management for Higher Productivity and Soil Health

Rita Fredericks

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Agriculture in the 21st century is subject to numerous challenges, such as declining soil fertility, climate change, environmental contamination, and increased food demand. Integrated Nutrient Management (INM) provides a sustainable approach with the integration of chemical fertilizers, organic manures, and bio-fertilizers to provide balanced nutrient supply, better soil health, and increased crop productivity. INM enhances soil physical, chemical, and biological quality, enhances nutrient-use efficiency, and reduces nutrient losses to leaching and volatilization, thus minimizing environmental risks. INM not only increases crop yield and quality but also reduces the cost of inputs, improves soil organic matter, enhances microbial diversity, and improves resistance to climatic stresses. Through the combination of short-term productivity enhancement with long-term ecologic balance, INM positions itself as a prime strategy for sustainable agriculture, resource preservation, and greenhouse gas mitigation.

Introduction

Agriculture in the 21st century is dealing with several challenges, which include growing demand for food, soil fertility depletion, climatic change, and the requirement of environmentally friendly farming practices. To address these demands, efficient use of natural resources is of prime concern. Dependent use of chemical fertilizers alone, although efficient in enhancing yield, tends to cause soil degradation, imbalance of nutrients, reduction in organic matter, and pollution of the environment in the long term.

Integrated Nutrient Management (INM) is a balanced and integrated strategy that stresses the judicious blending of chemical fertilizers, organic manures (e.g., farmyard manure, compost, and green manures), and bio-fertilizers (nitrogen-fixing bacteria, phosphate-solubilizing microbes, mycorrhizal fungi, etc.). This integration provides a sustained supply of macro- and micro-nutrients, improves nutrient use efficiency, enhances soil microbial activity, and maintains long-term soil productivity.

Through combining various sources of nutrients, INM not only enhances crop production and quality but also brings about soil health by improving soil structure, water retention, and biological processes. Furthermore, it reduces the loss of nutrients via leaching, volatilization, or fixation, and thus prevents environmental risks such as contamination of groundwater and greenhouse gas emissions.

Finally, INM is the basis of sustainable agricultural systems, combining short-term gains in productivity with long-term ecological equilibrium. Its implementation can be a key component for the attainment of increased yields, improved farm profitability, climate variability resistance, and natural resource conservation for future generations.

Objectives of INM

The main objective of Integrated Nutrient Management (INM) is sustainable crop production along with ecological balance and natural resource conservation. The specific objectives are:

To ensure soil fertility and productivity in the long run

INM ensures continuous replenishment of essential nutrients through a judicious mix of organic, inorganic, and biological sources. This approach prevents soil nutrient mining, sustains soil organic

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matter, and maintains soil fertility for future generations.

To ensure balanced nutrient supply to crops

Various sources of nutrients complement one another in fulfilling the nutritional needs of crops. Integrating chemical fertilizers with bio-fertilizers and organic manures, INM ensures an equilibrium supply of both macro- (N, P, K) and micro-nutrients (Zn, Fe, B, Mn, etc.) and thus prevents deficiencies or excesses that can limit plant growth.

To enhance physical, chemical, and biological characteristics of soil

The addition of organic matter enhances soil structure, porosity, and water-holding capacity. Bio-fertilizers stimulate microbial diversity and biological activity, whereas inorganic fertilizers replenish nutrient stores. Together, they sustain beneficial soil pH, cation exchange capacity, and nutrient cycling, thus enhancing general soil health.

For minimizing reliance on chemical fertilizers and encouraging eco-friendly agriculture

Excessive and ongoing use of synthetic fertilizers may cause soil degradation, nutrient deficiencies, and environmental contamination. INM minimizes chemical dependence by incorporating renewable organic resources and beneficial microorganisms, which encourages environmentally friendly and climate-resilient agricultural systems.

To improve crop yield, quality, and profitability

Balanced nutrient supply not only enhances crop yield but also enriches the nutritional status, storability, and market value of produce. Through cost reduction of inputs by minimizing chemical use and enhancing resource use efficiency, INM promotes farm profitability while ensuring soil and environmental health.

To help mitigate climate change and conserve resources

INM practices reduce greenhouse gas emissions, enhance sequestration of carbon by adding organic matter, and decrease the loss of nutrients. This conserves biodiversity, enhances ecosystem services, and promotes sustainable resource use.

INM Components

Integrated Nutrient Management comprises using various sources of nutrients together in such a way as to conserve soil fertility, improve nutrient use efficiency, and attain sustainable crop production. The key components are:

1. Organic Sources

Organic inputs contribute significantly towards the sustenance of soil health and fertility through the enhancement of its physical, chemical, and biological characteristics. Some of the prevalent organic sources are:

- ✓ Farmyard Manure (FYM): Furnishes a broad array of nutrients, enhances soil structure, increases microbial activity, and enhances water-holding capacity.
- ✓ Compost: Furnishes slow-release nutrients, recycles crop residues, and facilitates management of waste.
- ✓ Green Manure: Legume crops such as Sesbania and Dhaincha immobilize atmospheric nitrogen, enhance soil organic carbon, and inhibit weeds.
- ✓ Crop Residues: Straw, husk, and other residue recycling enriches soil organic matter and preserves soil fertility.
- ✓ Vermicompost: Humus-rich, plant growth stimulants, and beneficial microorganisms make up vermicompost, enhancing soil structure and nutrient availability.

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2. Inorganic Fertilizers

Chemical fertilizers are still a key part of nutrient management due to their rapid release of nutrients and capacity to satisfy crop requirement during critical stages of growth. Their use in an efficient manner is necessary to achieve enhanced yields.

- ✓ Macronutrients: Balanced use of nitrogen (N), phosphorus (P), and potassium (K) provides maximum plant growth and yield.
- ✓ Secondary and Micronutrients: Nutrients such as sulfur (S), zinc (Zn), iron (Fe), boron (B), and manganese (Mn) fix deficiencies and enhance quality attributes like oil content, protein content, and grain storability of crops.
- ✓ Site-Specific Nutrient Management: Fertilizer application through soil testing and crop need maximizes use efficiency and reduces losses.

3. Bio-Fertilizers

Bio-fertilizers are microorganisms that are alive and stimulate plant growth by fixing, mobilizing, or solubilizing soil nutrients. They are effective in decreasing dependence on chemical fertilizers and encouraging environmentally friendly farming.

Nitrogen Fixers: Rhizobium (legumes), Azotobacter, and Azospirillum fix nitrogen from the atmosphere and make it available to the plant.

- ✓ Phosphate Solubilizing Microorganisms (PSM): Transform insoluble phosphorus into soluble forms accessible to plants, enhancing phosphorus-use efficiency.
- ✓ Mycorrhizal Fungi: Develop symbiotic relationships with roots to enhance phosphorus, zinc, copper, and water absorption.
- ✓ Potassium Solubilizing Microbes (KSM): Release bound potassium as available fractions for uptake by plants.
- ✓ Plant Growth-Promoting Rhizobacteria (PGPR): Elaborate growth hormones, enhance nutrient acquisition, and boost plant resistance to stress.

Advantages of INM

Integrated Nutrient Management (INM) adoption presents various agronomic, ecological, and economic advantages. Through the integration of organic, inorganic, and biological sources of nutrients, INM promotes sustainable crop production while protecting natural resources. The significant advantages are:

Improves crop productivity through proper nutrition

INM ensures a constant and balanced delivery of vital nutrients, enhancing the efficiency in the use of nutrients and promoting plant growth throughout the season. This results in greater yields, improved crop quality, and nutritional content of the produce.

Enhances soil organic matter and microbial diversity

Organic matter and bio-fertilizers build soil organic carbon, boost enzymatic activity, and enhance populations of desirable microbes. This enhances soil biological processes like nutrient cycling, nitrogen fixation, and disease suppression, hence reviving soil vitality.

Decreases cost of cultivation and enhances farmer profitability

By minimizing the excessive use of expensive chemical fertilizers and using locally available organic materials, INM reduces the cost of inputs. Simultaneously, it enhances stability in yields and market price of the crops, resulting in more net income for the farmers.

Minimizes environmental pollution

Optimal application of fertilizers under INM minimizes the losses of nutrients via leaching, runoff, and volatilization. It prevents groundwater pollution,

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water body eutrophication, and greenhouse gas emission, hence promoting environmentally safe farming and ecological sustainability.

Enhances physical properties of the soil and its water-holding capacity

Use of organic manures and compost improves soil structure, porosity, and aggregation. Increased water infiltration and retention make soils drought- and climat-stress-resilient, ensuring sustainable crop production under changing weather conditions.

Increases resistance to pests, diseases, and climate stress

An optimally balanced nutrient regime under INM enhances plant vigor, pest- and disease-resistance, and abiotic stress tolerance to salinity, drought, and temperature.

Supports long-term agriculture sustainability

By sustaining soil fertility, minimizing reliance on non-renewable resources, and enhancing environmental balance, INM supports the long-term yield of agro-ecosystems as well as preserving natural resources for generations to come.

Practical Guidelines for INM

Practical and scientifically established guidelines must be followed by farmers for effective implementation of Integrated Nutrient Management, ensuring both greater productivity and sustainable soil health. Important recommendations are:

Soil testing prior to fertilizer application

Routine soil testing assists in the comprehension of nutrient status, soil pH, and organic matter levels. It gives a scientific rationale to apply fertilizers in the correct quantity, correct form, correct time, and correct method (4R nutrient stewardship). This prevents under- or over-application, enhances nutrient-use efficiency, and reduces input costs. Use 25–30% nutrients from organic sources and the remaining from chemical fertilizers Organic manures (FYM, compost, vermicompost) along with inorganic fertilizers should provide a balanced ratio of nutrients. Organic inputs enhance soil health, whereas chemical fertilizers cater to short-term crop nutrient requirements, and both ensure short-term productivity and long-term fertility.

Include bio-fertilizers with seeds or at planting time

Seed inoculation with Rhizobium, Azotobacter, Azospirillum, or PSM improves phosphorus solubilization and nitrogen fixation. Mycorrhizal fungus application increases phosphorus and micronutrient uptake. These practices enhance root growth, limit the use of chemical fertilizers, and encourage eco-farming. Employ crop residues and green manuring for recycling nutrients Adding crop residues (straw, husk, stalks) to the soil brings back nutrients into the system and increases soil organic matter. Increasing green manure crops such as Sesbania, Dhaincha, or cowpea introduces organic matter, fixes nitrogen, and enhances soil structure. These activities minimize the demand for external fertilizer and enhance soil fertility.

Adopt crop rotation and legume intercropping

Legume rotations (e.g., rice–wheat–mung bean) enhance soil nitrogen content through biological fixation. Intercropping systems (e.g., maize + cowpea, sorghum + pigeon pea) promote efficient use of nutrients, minimize pest/disease occurrence, and enhance soil fertility.

Implement site-specific nutrient management (SSNM)

Modify application of nutrients according to local soil, cropping pattern, and climate. Implement precision farming instruments (leaf color guides, nutrient decision support systems, GPS-based soil maps) in order to optimize the use of fertilizer.

Proper application timing and fertilizer application method

Split fertilizer application of nitrogen and sowing application of phosphorus and potassium enhance

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nutrient-use efficiency. Fertilizers must be applied at the root zone by techniques like band placement or fertigation to reduce losses.

Integrate INM with organic waste management

Utilize farm waste, kitchen waste, and agro-industrial residues (press mud, coir pith, biogas slurry) as compost or vermicompost. This not only solves waste disposal issues but also nutrient-enriches soils.

Conclusion

Integrated Nutrient Management (INM) is the foundation of sustainable agriculture since it encourages a harmonious and efficient nutrient use method. In contrast to sole dependence on chemical fertilizers, which can increase yields in the short term but weaken soil in the long term, INM balances organic manures, inorganic fertilizers, and bio-fertilizers to produce a durable and productive farming system. This method not only guarantees increased crop production and better quality of crops but also sustains soil health, increases microbial diversity, and promotes resilience to climate variability.

The use of INM leads to a significant decrease in cultivation costs, increased nutrient-use efficiency, and decreased environmental risks such as groundwater contamination and greenhouse gas emissions. It also leads to soil enrichment through recycling of organic matter, promotes ecosystem services such as nitrogen fixation and nutrient cycling, and increases conservation of resources. For farmers, INM means increased profitability, productivity over the long term, and increased sustainability of their farming businesses.

Given the rise of global issues such as climate change, food insecurity, and soil degradation, INM provides a viable, environmentally friendly, and science-based approach to achieve both food security and environmental sustainability. Thus, increasing INM practices through policy support, farmer awareness, and training is essential in creating a robust agricultural industry that can rise to the demand for food while maintaining natural resources for future generations.

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Significance of Vachellia nilotica in our life

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Botanical name: Vachellia nilotica | Hindi: बबूल | English: Babool

About

The Babool tree, scientifically known as Acacia nilotica, is a medium-sized deciduous tree characterized by its distinctive bipinnate compound leaves and rough, dark gray bark. Native to Africa and the Indian subcontinent, it adapts well to arid regions. The tree produces small, fragrant, pale yellow flowers in spherical clusters, eventually developing into long, twisted pods. Its thorny branches contribute to its resilience, deterring herbivores. Babool is valued for its hard and durable wood, extensively used in carpentry. Additionally, its bark and gum have traditional medicinal applications in Ayurveda and other traditional healing systems for various ailments.

Other name of Babool

Acacia nilotica, Indian Gum Arabic tree Babul, Thorn mimosa, Egyptian acacia, Thorny acacia, Babla, Black Babul, Babaria, Baval, Kaloabaval, Kikar, Gobbli, Karijali, Karivelan, Karuvelum, Babhul, Vedibabul, Babhula, Bambuda, Baubra, Sak, Kaluvelamaram, Karrivelei, Karuvael, Karuvelam, Nallatumma, Tumma, Tuma

Interesting Facts

Medicinal Uses: Babool finds an important place in Ayurvedic and Unani healthcare systems.

1. Extracts from the bark are employed in traditional medicine to treat various skin disorders and wounds.
2. Babool gum, known as "Babul gond," is used in Ayurveda for respiratory conditions and as a natural adhesive.
3. The Babool tree is known for its potential in managing dental issues, with twigs traditionally used as natural toothbrushes.
4. **Oral problems**
   Chewing small pieces of fresh bark of babool tree can be good for oral health. It not only help strengthen the teeth but heals the gum due to its Kashaya (astringent) property.
5. **Diarrhea and Lose motion**
   Babool bark helps to treat diarrhea and lose motion because Babool has Kashaya(astringent) and reduce Ama(Ama (toxic remains in the body due to improper digestion) properties which help to improve metabolism, give strenght to intestine and control diarrhea or lose motion
6. **Leucorrhea**
   Chew 5-8 Babool leaves and drink a glass of water in the morning daily to cure vaginal white discharge in female and Dhat rog in male due to its coolant and astringent effects.
7. **Cough and Cold**
   Babool Bark is helpful in the treatment of cold symptoms as well as relieving sore throat that is associated with cold and cough due to its Kapha balancing property which helps to melt excessive sputum and give relief from a cough and cold.
8. **Arthritis and Fractured bone**
   Babool gum works on arthritis pain as well as also helps in the fracture to fasten the union of fractured ends for proper healing of internal injuries when its taken orally due to its Vata balancing and Ropan(healing) nature.
9. **Wound**
   Babool gum is an excellent healer due to its Ropan (healing) and Kashaya(astringent) (properties. As a result, balool gum is used to heal and checks bleeding when applied externally minor wound or skin injury.
10. **Skin disease**
    Babool bark powder cures skin problems like eczema and fungal infection due to its Kashaya (astringent) quality.

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11. **Bleeding Piles**
    Babool powder shows good result in pain or bleeding piles due to its Sita (cold) potency and Kashaya (astringent) properties.
12. **Burn Injuries**
    Babool bark powder helps to cure burn injuries because it stimulates the healing process of burn injuries and controls the scar formation due to its Kashya(astringent) and Ropan(healing) property

Culture and Tradition:

1. Babool's hard and durable wood has cultural importance in carpentry and construction. It is also used to make tools, such as handles for agricultural implements.
2. It's twigs are used by several cultures as tooth brushes.
3. Farmers use Babool's leaves and pods as **animal feed**.
4. The bark of the Babul tree is high in tannins, which are used in the leather industry to tan animal hides and produce leather products such as shoes, belts, and bags.
5. It finds extensive use in traditional medicine systems such as Ayurveda and Unani.

Environmental Impact: The Babool tree (Acacia nilotica) plays a vital role in environmental conservation. Thriving in arid regions, it contributes to soil conservation with its deep-rooted system, preventing erosion. Its nitrogen-fixing abilities enhance soil fertility, supporting the growth of other plants. The tree offers shade, reducing surface temperatures and providing a habitat for diverse wildlife. Additionally, Babool's thorny branches act as a natural deterrent, protecting against overgrazing by herbivores. Its resilience to harsh climates makes it a valuable species for afforestation and reforestation efforts, promoting biodiversity and contributing to the overall health and sustainability of ecosystems

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Grow More Blackgram: An Analytical Study on Blackgram Cultivation Trends in India

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Introduction

Black gram (*Vigna mungo* L. Hepper) is an important annual legume belonging to the family Fabaceae. It is a self-pollinated crop characterized by an erect to semi-trailing growth habit with dense pubescence. India is considered the primary center of origin, and the crop is well adapted to a wide range of soils, particularly loamy soils and vertisols. Presently, it is extensively cultivated in Southeast Asia and parts of Africa due to its adaptability and short growth duration. Nutritionally, black gram is a rich source of protein, dietary fiber, and essential minerals, making it a vital pulse in human diets (Swaminathan *et al.*, 2022). It plays a key role in Indian culinary applications, especially in traditional preparations such as idli, dosa, and vada (Kanth et al., 2021). The tender pods are consumed as vegetables, while the processed flour is utilized in various food products and even in the formulation of herbal soap alternatives. Agronomically, black gram holds significant importance as a nitrogen-fixing legume, thereby enhancing soil fertility and contributing to sustainable cropping systems. It is widely adopted in intercropping and crop rotation systems due to its short duration, low input requirement, and economic returns. Its ability to improve soil health and its market demand make it a valuable crop in both subsistence and commercial agriculture. This paper presents data on the area, production, and productivity of blackgram in India (INDIASTAT) to emphasize the significance of pulse cultivation.

Time-Series Analysis of Blackgram Cultivated Area in India

The area under black gram cultivation in India has experienced significant variation over the 25-year period **(Fig 1.)** From 2000–2001 (3011 thousand hectares) to 2024–2025 (3023 thousand hectares), showing an overall marginal net increase of 0.004-fold. Initially, there was a steady increase, with the area rising from 3011 to 3550 thousand hectares by 2002–2003, registering a 1.18-fold increase over the base year. However, this was followed by a decline to 3169 thousand hectares in 2004–2005, and further to 2969 thousand hectares in 2005–2006 a 0.94-fold decrease compared to 2000–2001. The lowest point in the early years occurred in 2008–2009, where the area dropped to 2670 thousand hectares, representing a 0.89-fold decrease from the base year. A recovery phase followed, reaching 3267 thousand hectares in 2010–2011, close to the 2001–2002 levels. From 2014–2015 (3246 thousand hectares) onwards, a significant upward trend was observed, with the area increasing to 3624 thousand hectares in 2015–2016, and peaking at 5602 thousand hectares in 2018–

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2019, which marks an approximate 1.86-fold increase over the 2000–2001 baseline. However, after 2018–2019, the area under black gram declined sharply, first to 4533 thousand hectares in 2019–2020 (a 0.81-fold decrease from the peak), and further to 4143 thousand hectares in 2020–2021, before a brief recovery to 4633 thousand hectares in 2021–2022. The trend reversed again with a continuous decline to 4002 thousand hectares in 2022– 2023, 3536 thousand hectares in 2023–2024, and back to 3023 thousand hectares in 2024–2025, nearly identical to the area recorded in 2000–2001. Overall, while the long-term trendline shows a gradual increase, the area under black gram cultivation has returned to its initial level, indicating that the expansion phase (2015–2019) was not sustained. These fluctuations highlight the influence of changing agricultural priorities, market dynamics, climatic stress, and policy shifts on black gram cultivation in India.

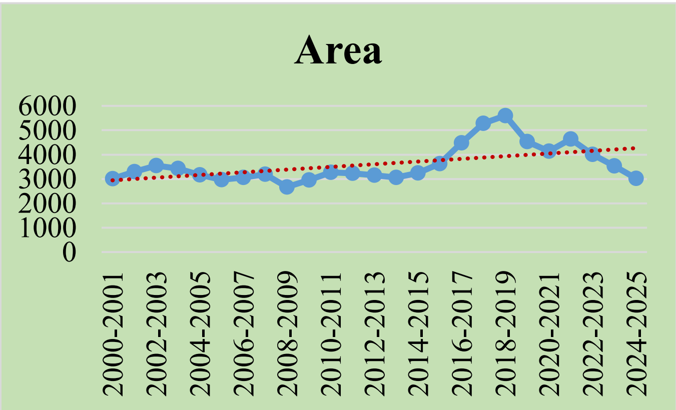


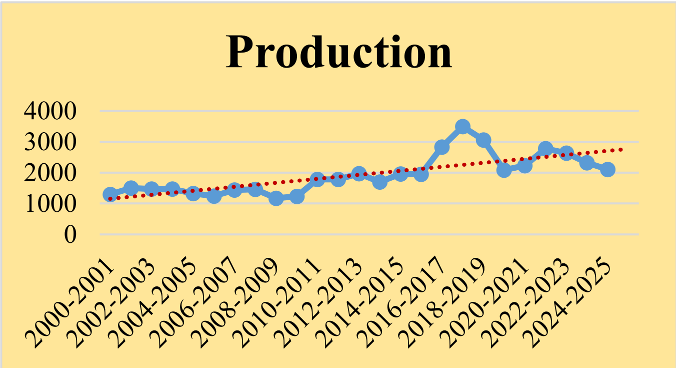
Fig. 1. Area under the cultivation of blackgram in India

Trends and Variability in Blackgram Production in India

Black gram production in India has shown many ups and downs over the last 25 years **(Fig 2.)**. In 2000–2001, the country produced about 1296 thousand tonnes of black gram . In the next year, production increased to 1499 thousand tonnes, showing a 1.16 times rise. For a few years, production remained almost steady, staying between 1440–1470 thousand tonnes. However, in 2008–2009, production dropped sharply to 1175 thousand tonnes, which was a 19% decrease from the previous year and the lowest during the entire period. After that, production started to improve again, reaching 1779 thousand tonnes in 2010–2011, which was 1.44 times higher than the previous year. From 2011 to 2015, production slowly increased and stayed between 1785 and 1959 thousand tonnes. A major jump was seen in 2016–2017, when production reached 2832 thousand tonnes, followed by the highest production in the entire period in 2017–2018, at 3492 thousand tonnes which was nearly 2.7 times higher than the level in 2000–2001. However, this was followed by a sharp decline. In 2018–2019, production fell to 3060 thousand tonnes, and in 2019–2020, it dropped further to 2081 thousand tonnes, which was a 40% decrease from the 2017–2018 peak. Some recovery happened in the next two years, with production reaching 2776 thousand tonnes in 2021–2022. But it declined again to 2106 thousand tonnes by 2024– 2025. Overall, black gram production increased from 1296 to 2106 thousand tonnes over 25 years, showing a 1.62 times growth. But recent years have seen a falling trend, which could be due to climate issues, pest attacks, or farmers shifting to other crops. The data shows that while black gram production improved greatly over time, it is now facing new challenges that need attention.

Fig. 2. Analysis of blackgram production in India

Progression of Blackgram Productivity in Indian Agriculture



The productivity of black gram in India, measured in kilograms per hectare, has generally increased over the past 25 years, even though there were some ups and downs **(Fig. 3)**. In 2000–2001, the average productivity was 431 kg/ha. It rose slightly in 2001–2002 to 454 kg/ha (1.05 times increase), then dropped to 415 kg/ha in 2002–2003 (0.91 times decrease) and stayed close to that level for the next few years. From 2004–2005 to 2009–2010, productivity ranged between 418 and 440 kg/ha, showing only minor fluctuations. A major improvement happened in 2010–2011, when productivity rose to 545 kg/ha, a 1.30-fold increase compared to the previous year. This upward trend continued with 552 kg/ha in 2011–2012, and 625 kg/ha in 2012–2013, which was 1.47 times higher than the base year 2000–2001. However, in 2013–2014, productivity dipped to 555 kg/ha before climbing again to 604 kg/ha in 2014– 2015. A slight drop occurred in 2015–2016 to 537 kg/ha, but the next two years showed strong growth: 632 kg/ha in 2016–2017, and 662 kg/ha in 2017– 2018—the highest so far, and a 1.54 times increase from 2000–2001. After peaking, productivity dropped sharply to 546 kg/ha in 2018–2019, and further down to 459 kg/ha in 2019–2020, marking a 0.69-fold decrease from the 2017–2018 peak. However, a recovery followed, with productivity increasing to 538 kg/ha in 2020–2021, and then to 599 kg/ha in 2021–2022. In 2022–2023, it rose again to 657 kg/ha, and slightly dipped to 656 kg/ha in 2023–2024. By 2024–2025, black gram productivity reached its highest point in the dataset—697 kg/ha, which is a 1.62-fold increase from the year 2000– 2001. In summary, despite some setbacks, black gram productivity in India has steadily improved over the years, especially after 2010. This indicates better farming practices, improved hybrid seeds, and better crop management, even during times when area and production declined.

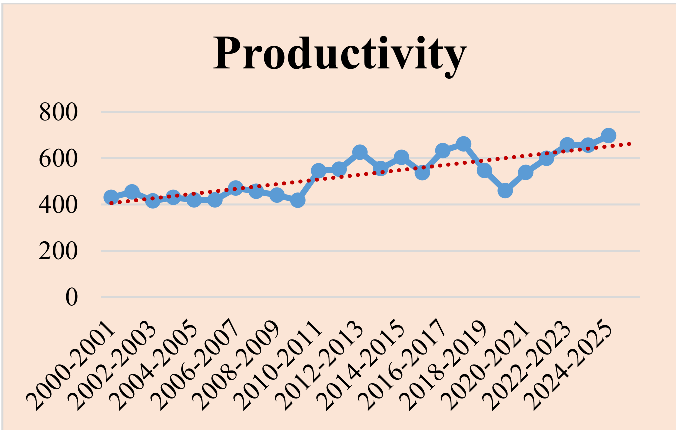


Fig. 3. Blackgram productivity in blackgram

Relative Assessment of Blackgram Cultivation Trends in India

Over the past 25 years, the area under black gram cultivation, its total production, and productivity have shown varied patterns in India **(Fig.4)**. In 2000– 2001, black gram was cultivated on 3011 thousand hectares, producing 1296 thousand tonnes with a productivity of 431 kg/ha. From 2000 to 2010, the area remained mostly stable, ranging between 2900 and 3300 thousand hectares, while production hovered between 1200 and 1500 thousand tonnes, and productivity stayed below 500 kg/ha. A major change occurred after 2010–2011, when all three parameters showed growth. Area expanded from 3267 thousand ha in 2010–2011 to a peak of 5602 thousand ha in 2018–2019. Production also reached its highest at 3492 thousand tonnes in 2017–2018, nearly 2.7 times the 2000 level. However, after this peak, both area and production declined sharply—by 2024–2025, area reduced to 3023 thousand ha and production to 2106 thousand tonnes, close to early 2000s levels. In contrast, productivity showed a steady long-term increase, from 431 kg/ha in 2000–2001 to 697 kg/ha in 2024–2025, indicating a 1.62-fold improvement. Even during years when area and production fell such as 2019–2020 to 2024–2025 productivity either remained stable or increased, suggesting better farming practices, improved seed quality, or more efficient management. In conclusion, while black gram cultivation area and total production in India peaked and then declined in recent years, productivity has shown consistent improvement, reflecting advancements in agricultural techniques. This indicates that farmers are producing more blackgram per unit area despite cultivating less land in the later years.

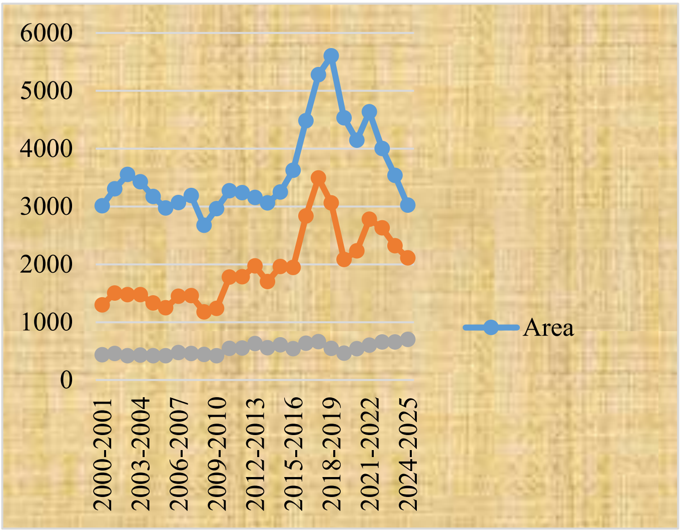


Fig. 4. Comparison of blackgram cultivation in India

CONCLUSION

Over the last 25 years, blackgram cultivation in India has undergone significant shifts, marked by fluctuations in area and production but a consistent rise in productivity. While the area under blackgram and total output peaked around 2017– 2019, both have since declined, returning to early-2000s levels by 2024–2025. In contrast, productivity has steadily improved, reaching its highest ever in 2024–2025. This suggests that despite challenges such as climate stress, pest issues, and shifts in farmer preferences, technological advancements, improved agronomic practices, and better-quality seeds have enabled more efficient blackgram production. The trend underscores the importance of sustaining productivity gains while addressing the factors behind the declining area and production to ensure long-term food security and farmer profitability.

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Gamification in Education: Transforming the Learning

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This article explores the burgeoning role of gamification in revolutionizing educational practices. By integrating game-like elements into learning environments, gamification aims to enhance student engagement, motivation, and knowledge retention. We delve into the core concepts and underlying theories of gamification, examine its diverse applications within education and agriculture, and review recent research highlighting its effectiveness. The article also addresses the advantages and challenges associated with this innovative approach, concluding with a forward-looking perspective on its potential to reshape India's educational landscape to meet contemporary demands.

Introduction

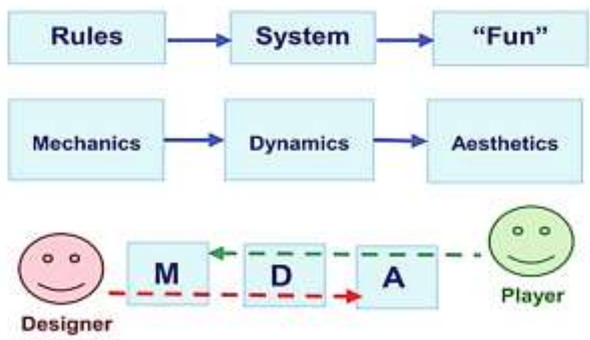
"Play is our brain's favorite way of learning," a sentiment that underpins the growing interest in gamification. This powerful strategy leverages the compelling allure of games to enrich non-game contexts, transforming passive reception into active participation. The concept of "gamification" gained traction around 2010, popularized at conferences and introduced in universities. Its relevance surged during the pandemic, as online teaching necessitated novel engagement strategies. Gamification is not merely about playing games; it's about strategically applying game-based mechanics, aesthetics, and thinking to motivate action, promote learning, and solve problems. This article unpacks gamification's multifaceted nature, exploring its fundamental concepts, psychological theories, practical applications (especially in India and agriculture), and its advantages and challenges, aiming to illuminate how it fosters a more interactive, personalized, and effective learning journey.

2. Concept and Theories of Gamification

2.1 Defining Gamification

At its core, gamification is the strategic integration of game elements and design principles into non-game contexts. The Oxford Dictionary defines it as "the application of typical elements of game playing to other areas of activity, typically as an online marketing technique to encourage engagement with a product or service." Karl Kapp offers a more education-centric definition: "Using game-based mechanics, aesthetics and game thinking to engage people, motivate action, promote learning, and solve problems." This highlight leveraging specific game components to enhance motivation and engagement.

Key elements include Points, Levels, Badges/Trophies, Leaderboards, Challenges/Quests, Rewards, Avatars, Progression, and Cooperation/Competition. These are understood through frameworks like the MDA (Mechanics, Dynamics, Aesthetics) framework. Mechanics are specific components (e.g., points); Dynamics are emergent behaviors (e.g., competition); Aesthetics refer to emotional responses (e.g., satisfaction). A well-designed system carefully considers how these interact to create effective learning.



2.2 Theories Underpinning Gamification

Several psychological theories explain gamification's effectiveness:

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2.2.1 Fogg's Behavior Model (FBM)

This model posits behavior change occurs when three factors converge: **Motivation**, **Ability**, and a **Trigger**. Motivation is the desire; Ability is the capacity (often simplified by gamification); Trigger is the prompt. Gamification strategically manipulates these to guide learners towards desired behaviors.

2.2.2 Self-Determination Theory (SDT)

SDT focuses on intrinsic motivation and psychological needs: **Autonomy** (choice/control), **Competence** (effectiveness), and **Relatedness** (connection). Gamification addresses these by offering choices, providing feedback on progress, and fostering social interaction, shifting learning to an intrinsically rewarding activity.

2.2.3 Theory of Gamified Learning

This theory suggests that thoughtful integration of game elements with instructional material positively impacts Engagement, Motivation, Knowledge Acquisition, and Skill Development. The interplay between game elements, instructional design, and learner psychology is crucial for successful gamified learning.

3. Gamification in Education: Applications and Impact

Gamification aims to make learning dynamic and enjoyable, with Gabe Zichermann noting it "improves the abilities to learn new skills by 40%."

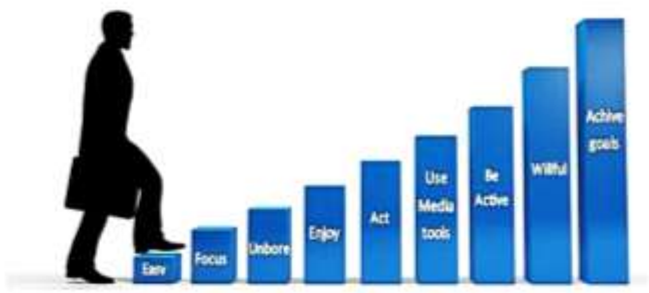
3.1 Principles of Gamification in Education

Key principles include Goal Orientation, Achievement, Reinforcement, Competition, and Fun Orientation, all designed to enhance the learning process.

3.2 The Role of Gamification in Education

Gamification transforms learning by:

1. **Engaging Students:** Captures and sustains interest.
2. **Motivating Students:** Uses rewards and progress tracking.
3. **Improving Knowledge Absorption:** Facilitates deeper understanding through interactivity.
4. **Fostering Collaboration:** Encourages peer interaction in team challenges.
5. **Making Learning Interactive:** Promotes active participation.
6. **Facilitating Personalized Learning:** Allows learners to progress at their own pace.
7. **Instant Feedback:** Enables prompt understanding and correction of mistakes.



3.3 Classification of Players in Educational Contexts

Understanding learner types is crucial:

- **Achievers:** Thrive on challenges, recognition, and mastery.
- **Explorers (Free Spirits):** Driven by discovery, choices, and hidden content.
- **Socializers:** Excel in collaborative activities and social interaction.
- **Disruptors:** Seek to bypass obstacles, can advocate for change.
- **Creators:** Motivated by generating new ideas and content.

3.4 Types of Training Games

Gamification extends to various training scenarios:

- **Communication Games** (e.g., "Two Truths and a Lie"): Enhance team-building and discernment.
- **Problem-Solving Games** (e.g., "Picture Pieces Game"): Teach teamwork and individual contributions.
- **Adaptability Games** (e.g., "The Paper Tower"): Emphasize planning and flexible thinking.
- **Trust Exercises** (e.g., "Mine Field," "Trust Fall"): Build relationships and effective communication.

3.5 Gamification in India

India has widely adopted gamification:

- **Education Sector:** BYJU'S, Toppr, Vedantu use interactive learning and quizzes.
- **Corporate Sector:** Zoho, Wipro, Infosys integrate gamified training.
- **Health & Fitness:** Fitbit, HealthifyMe, FitIndia Movement use challenges and rewards.
- **Government and Social Campaigns:** Swachh Bharat Abhiyan and Gujarat's "Ek Kadam Agal" use gamified apps.
- **Agriculture:** Gujarat Agricultural University (GAU) and the Gujarat Government introduced gamification in farmer training as early as 1996, using tools like modified Snakes and Ladders games to boost engagement and knowledge acquisition.

Educational apps like Kahoot, Quizizz, Duolingo, Classcraft, Khan Academy, and Prodigy, as well as professional platforms like Udacity, edX, LinkedIn Learning, and Coursera, all exemplify successful gamification through points, levels, leaderboards, rewards, and certificates.

4. Review of Related Research Studies

Research consistently demonstrates gamification's positive impact on learning outcomes:

A **Germany study by Hauge *et al.* (2013)** on case study games ("Cosiga," "Beware," "SBCE") showed improvements in soft skills (communication, teamwork), declarative knowledge (NPD, supply chain risks), procedural knowledge (managing development, risk application), and strategic knowledge (long-term decision impacts).

In **Nigeria, Omotosho *et al.* (2019)** found a highly positive perception (52% highest rating) among students (n=50) using a gamified approach for farm practices at Landmark University, highlighting enhanced engagement and satisfaction.

McKim *et al.* (2020) at Michigan University, USA, observed a positive shift in teacher perceptions (n=50) regarding game utilization in agricultural education PDPs, indicating increased comfort with integration.

Singh's (2023) research across **India and Tanzania** on interactive cardboard games for cotton growers showed compelling knowledge gains. In Punjab (n=120), low knowledge dropped from 70% to 1.66%; in Madhya Pradesh (n=40), it dropped from 40% to zero; and in Tanzania (n=40), from 52.5% to zero. High knowledge significantly increased across all regions, demonstrating the games' effectiveness and high satisfaction levels.

A **Bangalore study by Satheeshkumar *et al.* (2023)** (n=200) revealed:

- **Access Modes:** 51.50% preferred smartphones.
- **Concept Understandability:** 66.50% were "sure" gamification makes concepts clearer.
- **Motivation to Learn:** 95.50% agreed it motivates learning.
- **Extension to Educational Institutions:** 97% supported its extension.

- **Feelings:** 58.50% felt "happy" and 33% "excited" playing games over regular courses.
- **Role in Education:** Respondents largely agreed gamification improves attendance, confidence, involvement, career approach, performance, and overall learning experience.

These studies collectively provide robust evidence for gamification's positive impact on learning outcomes, engagement, motivation, and knowledge retention across diverse contexts.

5. Advantages and Challenges of Gamification

5.1 Advantages of Gamification in Education

Gamification offers numerous benefits:

- **Better Learning Experience:** Transforms passive learning into active, immersive, and enjoyable engagement.
- **Instant Feedback:** Allows immediate understanding and correction of mistakes.
- **Better Learning Environment:** Fosters psychological safety, viewing failure as growth.
- **Learning at an Individual Pace:** Caters to diverse learning styles.
- **Failure as an Opportunity:** Reframes mistakes as chances to learn, encouraging persistence.
- **Behavioral Change:** Encourages desired learning behaviors through motivational triggers.
- **Increased Engagement and Motivation:** Leverages inherent human desires for play and challenge.
- **Improved Knowledge Retention:** Active participation leads to better long-term memory.
- **Development of Soft Skills:** Fosters communication, collaboration, and critical thinking.
- **Personalized Learning Paths:** Tailors content and challenges to individual needs.

5.2 Challenges of Gamification in Education

Implementing gamification effectively faces hurdles:

- **Lack of Understanding:** Superficial understanding can lead to ineffective outcomes.
- **Failure to Integrate into Curriculum:** Must be integral, not an add-on, for meaningful value.
- **Overemphasizing Rewards/Punishments:** Can diminish intrinsic motivation if overused.
- **Design Complexity:** Requires expertise in instructional and game design.
- **Technological Infrastructure:** Requires adequate tech and internet access.
- **Resistance to Change:** Educators and students may initially resist new approaches.
- **Maintaining Balance:** Difficult to balance challenge, competition, and learning outcomes.
- **Cost and Resources:** Developing high-quality platforms can be resource-intensive.

Addressing these challenges requires careful planning, professional development, and a nuanced understanding of game elements' enhancement potential.

6. Conclusion

Gamification powerfully demonstrates that learning can be an engaging and enjoyable journey. Its strategic integration significantly boosts knowledge retention, fosters deeper engagement, and cultivates confidence across diverse subjects and age groups. From enhancing farming skills to revolutionizing language acquisition, gamification transforms passive learning into an active, hands-on, and intrinsically motivating endeavor. The positive

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outcomes in performance, social interaction, and competence development highlight the urgent need for wider adoption and further research. In India, gamification offers a promising pathway to modernize education by aligning teaching with contemporary technological and industry demands, making it dynamic and impactful.

7. Future Thrust

The journey of gamification in education is still unfolding. To fully harness its transformative power, key areas for future development include:

- **Further Research:** Explore effectiveness across a broader spectrum of subjects and age groups.
- **Integration with Emerging Technologies:** Seamlessly integrate AI, VR, and AR for immersive and personalized learning.
- **Curriculum Alignment and Teacher Training:** Make gamification an integral part of curriculum design with robust professional development for educators.
- **Collaborative Ecosystems:** Foster partnerships among educators, designers, and policymakers for customized solutions.
- **Addressing Challenges:** Continuously work to ensure equitable tech access, prevent over-reliance on extrinsic rewards, and simplify design processes.

By embracing these thrusts, gamification can truly revolutionize learning, making education more engaging, relevant, and capable of addressing the dynamic demands of the global economy.

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Watershed Management with Horticulture

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Watershed can be defined as a unit of area that covers all the land which contributes runoff to a common point or outlet and surrounded by a ridge line. A watershed is defined as any spatial area from which rain or irrigation water is collected and drained through a common point.

The project addressed watershed degradation through soil and moisture conservation on arable and non-arable land. Introduction of horticulture and livestock improvement programs, training of staff in implementing agencies, and interactive planning with beneficiaries were among the more specific objectives. Watershed management was mainstreamed. The key characteristics of a watershed that drive management approaches are the integration of land and water resources, the causal link between upstream land and water use and downstream impacts and externalities, the typical nexus in upland areas of developing countries between resource depletion and poverty, and the multiplicity of stakeholders. Watershed management approaches need to be adapted to the local situation and to changes in natural resource use and climate.

Management of the environment has been primarily focused on specific issues such as air, land, and water. Most efforts have resulted in decreasing pollutant emissions to air and water, improved landfills, remediation of waste sites and contaminated groundwater, protection of rare and endangered species, design of best management practices to control water and contaminant runoff, and much more.

Watershed management provides a framework for integrated decision-making to help: assess the nature and status of the watershed; identify watershed issues; define and re-evaluate short and long-term objectives, actions and goals; assess benefits and costs; and implement and evaluate actions.

Adopting a watershed approach is founded on the basis that Alberta's water resources must be managed within the capacity of individual watersheds and that all Albertans recognize there are limits to the available water supply. What happens on the land and water in a watershed can affect the water supply that rivers provide. While land and water are closely linked, these resources have not historically been managed in a fully integrated manner. Focusing efforts at the watershed level provides a comprehensive understanding of local management needs, and encourages locally led management decisions.

Principles of watershed management

The main principles of watershed management based on resource conservation, resource generation and resource utilization are:

- Utilizing the land based on its capability.
- Protecting fertile top soil.
- Minimizing silting up of tanks, reservoirs and lower fertile lands.
- Protecting vegetative cover throughout the year.
- In situ conservation of rain water.
- Safe diversion of gullies and construction of check dams for increasing ground water recharge
- Increasing cropping intensity through inter and sequence cropping.
- Water harvesting for supplemental irrigation.

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- Maximizing farm income through agricultural and horticulture related activities such as dairy, poultry, sheep, and goat forming.
- Improving infrastructural facilities for storage, transport and agricultural marketing,
- Improving socio - economic status of farmers

Objectives of watershed management

- Recognition of watersheds as a unit for development and efficient use of land according their land capabilities for production.
- Flood control through small multipurpose reservoirs and other water storage structures at the head water of streams and in problem areas.
- Adequate water supply for domestic, agricultural and industrial needs.
- Abatement of organic, inorganic and soil pollution.
- Efficient use of natural resources for improving agriculture and allied occupation so as to improve socio-economic conditions of the local residents.
- Expansion of recreation facilities such as picnic and camping sites.

Crops for watershed

Fruits: Mango, Jack, Tamarind, sapota, cashew, Jamun, Guava, Ber, Anona, Amla, Carmbola, Phalsa, Bael, Kokum, Fig, papaya, Roseapple etc.

Vegetables: Tomato, Brinjal, Chillies, Cow pea, Drumstick, Curryleaf and Cucurbits.

Flower crops: Jasmine, Crossandra, Barlaria, Champaka, Nerium.

Medicinal and aromatic Plants: Amla, Jatropa, Aloevera, Ashwagandha, Bael, Neem, Annota, Bursera, Lemon grass, Citronella, Khus grass, Palma rosa, Henna, Tylophora, Periwinkle, Sappan wood, Karonda, *Terminaliaarjuna.*

Techniques for sustainable yield under watershed

The techniques using for getting sustainable yield under watershed consists use of drought tolerant varieties, in-situ grafting, root stock selection, deep planting and bigger basins, add plenty of organic matter, mulching and other soil and water conservation practices, border planting with tree *spp.* alternate row irrigation for closely spaced vegetables, drip irrigation, nursery production, kitchen garden, nutritional garden, school garden, small scalecottage industries for value addition and processing, vermicompost making using horticulture waste and mushroom cultivation.

Benefits derived from watershed methodology

Benefits obtained from watershed methodology includes increasing in crops yields in dry land farming, reduction in soil erosion, covering of barren hill slopes by vegetation, large tracts of marginal lands brought under dry land horticulture, agro-horti and agro-forestry systems development, harvesting of water resources through nala bunds, farm ponds, gully embankments, regeneration of grass lands for more fodder and grass and the farmers income increased considerably.

The Scales of intervention in Watershed Management

Watershed management programs generally adopt the micro-watershed level as the basic management unit, since this allows the integration of land, water, and infrastructure development and the inclusion of all stakeholders in a participatory process, for example, in northeastern Brazil where the approach allowed the needs and interests of local groups to be integrated. The micro-watershed has proved a flexible and practical unit for project implementation and has reduced costs. However, the definition of a micro-watershed needs to be adapted to the social, administrative, and physical context. Best practice is that choice of scale should be driven by a participatory analysis of problems throughout the watershed, preferably within a broader watershed planning framework, as was done in the Loess II Project in China. Based on this, programs can be clear from the beginning about the proposed scale of interventions and the socioeconomic, environmental, and technical criteria for defining the micro-catchment and for selecting which micro-catchments to target.

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The Rise of Biofertilizers: Are They Replacing Chemicals on Indian Farms?

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As Indian agriculture faces the twin challenges of environmental degradation and rising input costs, farmers and policymakers alike are rethinking long-held practices. Among the most promising shifts is the adoption of biofertilizers—organic formulations that use beneficial microbes to enhance soil fertility. Once considered niche, these inputs are now seeing widespread interest. But can they truly replace conventional chemical fertilizers, or are they merely complementary? This article explores the evolving role of biofertilizers in India, examining scientific developments, policy support, startup innovations, and their impact on farm productivity.

Introduction to Biofertilizers-

Biofertilizers are living microbial products that enrich the soil by making nutrients more accessible to plants. Unlike chemical fertilizers, which offer a quick nutrient fix, biofertilizers work more gradually—fixing atmospheric nitrogen, mobilizing phosphorus, and stimulating natural growth hormones. They help **revitalize the soil ecosystem**, often damaged by years of over-reliance on synthetic inputs.

Common types include *Rhizobium*, *Azospirillum*, *Azotobacter*, mycorrhizal fungi, and blue-green algae, each tailored to specific crops and soil conditions.

A Market on the Move-

The Indian biofertilizer market is growing rapidly—estimated to reach over **₹1,275 crore (USD 153 million) by the end of 2025**, with further growth projected into the next decade. This expansion is driven by:

Rising demand for organic produce

High chemical input costs

Government-backed sustainability programs

Northern states such as Punjab, Haryana, and Uttar Pradesh are emerging as key adoption zones, where intensive farming has strained soil health and opened doors to eco-friendly alternatives.

ICAR's Role and Scientific Backing-

India's apex agricultural research body, **ICAR (Indian Council of Agricultural Research)**, has been pivotal in developing and validating biofertilizer strains suited to Indian conditions. According to ICAR trials:

Biofertilizers can replace up to 25% of nitrogen and phosphorus fertilizers in several major crops without compromising yield.

- Yield increases of **10–30%** have been observed in fields using biofertilizers alongside reduced chemical inputs.
- Additional benefits include improved soil texture, better water retention, and disease resistance.
- This evidence is shifting perceptions—biofertilizers are no longer seen as just organic "add-ons" but as viable contributors to farm productivity.

The Startup Ecosystem: Innovation in the Soil-

A new wave of Agri-biotech startups is propelling this movement forward. Companies such as:

IPL Biologicals and **T. Stanes** are developing advanced microbial consortia.

Kribhco, in collaboration with Novonesis, launched ***Rhizosuper***—a commercial mycorrhizal biofertilizer for root health and nutrient efficiency.

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Super Crop Safe Ltd. introduced *Super Gold WP+*, combining beneficial fungi with trace minerals to enhance uptake and plant growth.

These products are being distributed through mobile platforms, Agri-retailers, and even doorstep delivery models, improving accessibility for small and marginal farmers.

Government Policy & Support-

India's agricultural policy has embraced biofertilizers as part of its sustainability agenda. Supportive initiatives include: **Paramparagat Krishi Vikas Yojana (PKVY)** and the **National Mission on Sustainable Agriculture (NMSA)**, which offer financial incentives for organic inputs. Amendments to the **Fertilizer (Control) Order (FCO)** now cover quality standards and registration of biofertilizers and bio-stimulants. Awareness campaigns and Kisan Melas have introduced biofertilizer use at the village level. Still, gaps remain in regulation enforcement and farmer education, especially in underserved regions.

Farmer Voices: Real-World Perspectives-

To ground the narrative in human stories, here are verbatim insights from Indian farmers and practitioners:

"In field trials … a 500 ml bottle of nano urea can replace one bag of conventional urea… it is proven to increase the crop yield by an average of 8 per cent … while reducing soil, water and air pollution." — ICAR-backed nano-urea initiative, shared by an Indian farmer. *(Source -Reddit)*

"The biofertilizer has already reached over 25,000 farmers in Odisha … a quiet revolution … to produce liquid biofertilizer." — Community-led manufacturing model partnered with CSIR-NBRI in Odisha. (*Source -Reddit, The Times of India)*

These statements reflect the impact of locally produced, affordable bio-inputs and how innovation is reaching marginalized farming communities.

Real Challenges on the Ground-

Despite the promise, several hurdles limit widespread adoption:

Lack of farmer awareness: Many smallholders still don't trust biofertilizers or don't know how to use them correctly.

Quality control: Product viability varies widely due to storage issues and poor regulation enforcement.

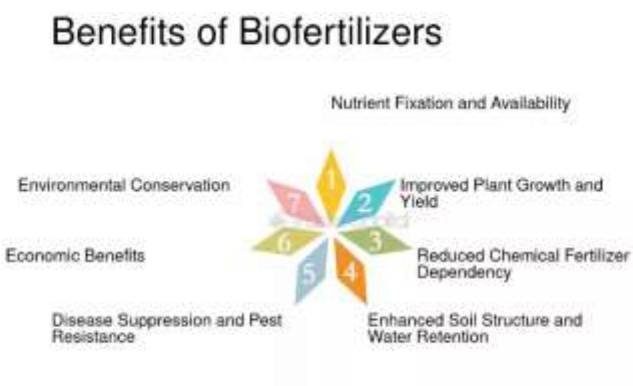
Distribution gaps: Many rural regions still rely on agro-dealers who don't stock or promote biofertilizers.

For meaningful progress, these issues need targeted interventions through public-private partnerships and better training for extension workers.

Looking Ahead: A Replacement or a Reinforcement?

In most cases, biofertilizers are not yet ready to completely replace chemical fertilizers—but they are proving to be a powerful **complement**. The emerging consensus among scientists, agronomists, and even traditional farmers is clear: the future lies in **integrated nutrient management**, where biofertilizers play a key role in reducing dependency on chemicals, restoring soil vitality, and improving farm economics.

The path forward isn't either/or—it's smarter and more balanced.



(Source: Faster Capital summary of agricultural research developments)

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Summary of Infographic Highlights-

Higher Nutrient Efficiency: Biofertilizers deliver nutrients more gradually and effectively (up to ~80% plant uptake), compared to only ~30–50% from chemical fertilizers.

Yield Benefits: Trials indicate yield improvements of approximately 10–30%, along with enhanced protein and nutrient content in crops.

Environmental Gain: Reduced soil pollution, minimized eutrophication of water bodies, and lower greenhouse gas emissions.

Challenges: Biofertilizers face issues like reduced shelf life, sensitivity to storage conditions, and uneven viability under stress conditions

Conclusion-

The rise of biofertilizers in India is more than a green trend; it's a quiet revolution reshaping how we grow food. With the right mix of research, innovation, and policy, these living inputs could well be the key to making Indian agriculture more resilient, productive, and sustainable.

The soil may still look the same—but what's happening beneath the surface is changing everything. Here's a professionally styled infographic illustrating the core benefits and challenges of biofertilizers in Indian agriculture. It highlights boosts in nutrient use efficiency, yield improvement, and soil health, along with the key limitations like shelf life and storage sensitivity.

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Recommended dose of herbicide on various rabi season crops

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Introduction

Herbicides play a crucial role in modern agriculture, especially during the cultivation of crops in the rabi season. Rabi crops, also known as winter crops, are sown in the cooler months and the harvested in the spring. These crops include wheat, barley, mustard, pea, lentils, chickpea and various vegetables. While the rabi season provides favorable conditions for crop growth, it also creates an environment conducive to the growth of unwanted weeds. Weeds compete with crops for vital resources such as sunlight, water, and nutrients, thereby reducing yield and quality. To combat this challenge, herbicides are widely used in *rabi* season crops to control weed growth and ensure optimum productivity. Herbicides are chemical compounds specifically designed to target and eliminate weeds. They act by interfering with essential physiological processes of weed plants, inhibiting their growth and development. Unlike traditional methods of weed control such as hand weeding or mechanical cultivation, herbicides offer several advantages. They are efficient, cost-effective, and can be applied on a large scale, covering extensive agricultural areas. Additionally, herbicides provide selective control, targeting weeds while minimizing the impact on the desired crops. This selectivity allows farmers to effectively manage weed populations while ensuring the healthy growth and development of rabi season crops. The use of herbicides in rabi season crops begins with careful planning and consideration of the specific weed species prevalent in the region. Different herbicides are available for different weed types, and selecting the appropriate herbicide is crucial for successful weed management. Farmers must consider factors such as the weed spectrum, growth stage of the crops, soil conditions, and environmental considerations when choosing herbicides. They must also adhere to proper application techniques, dosage rates, and timing to maximize effectiveness and minimize any potential negative impact on the environment.

Herbicide Application Timing

The objective should be to keep the crop weed free by the critical period of crop weed competition.

1. **Pre-sowing**: it is application of herbicides before the crop is sown or planted.
2. **Pre-emergence**: Pre-emergence herbicides are applied before weed seeds germinate or before weed emergence.
3. **Post-emergence**: herbicides are designed to be applied after crop emerged from the soil and before the weeds reach a certain growth stage.

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Recommended herbicide in *rabi* season

Herbicide name & approved Crops	Weed species	Dosage /ha a.i. (gm/ Kg)	Dosage /ha Formulation in (gm/ml /Kg/ ltr)	Dilution In Water (Litres)	Timing of appliction
Atrazine 50% WP					
Maize	*Digera arvensis, Echinochloa spp Eleusine Spp. Xantheium strumarium Brachiaria sp, Digitaria sp, Amaranthus viridis*	0.5-1.0 kg	1-2 kg	500-700	pre-emergence
Carfentrazone ethyl 40% DF					
Wheat	*Chenopodium album, Melilotus Indica, Melilotus alba, Medicago denticulata,Lathyrus aphaca, Analgalis arvensis, Vicia sativa, Circium arvense,Rumex sp,Malwa sp.*	20gm	50 gm.	400	(25-35 DAS)
Clodinafop- propargyl 15%WP					
Wheat	*Phalaris minor(Canary grass)*	60gm	400 gm.	375-400	30 DAS
Clodinafop- propargyl 15% w/w DF					
Wheat	*Phalaris minor(Canary grass)*	60gm	400 gm.	500	30-35 DAS
2,4-D Dimethyl Amine salt 58% SL					
Maize	Board leaf weeds	0.5kg	0.86	400-500	25-30 DAS
Wheat	*Chenopodium album, Fumaria parviflora, Melillotus alba, Vicia sative, Asphodelus tenuifolius, Convolvulus arvensi*	0.5-0.75 kg	0.86-1.29	500-600	25-30 DAS
Potato	*Chenopodium album, Asphodelus tenuifolius, Anagalis arvensis, Convolvulus arvensis, Cyperus iria, Portulaca oleracea*	5.30 kg	3.44	400	20-25 DAS
2,4-D Sodium salt Technical (having 2,4-D acid 80 % w/w)					
Grapes	*Convolvulus spp. Tridax procumbens*	2.0	2.5	500	30-35 DAS
Sugarcane	*Boerhaavia diffusa Chenopodium album,Tribulus terristris, Portulaca oleracea Xanthium spp., Convolvulus arvensis*	2.0-2.6	2.5-3.25	600-900	30-35 DAS
Non crop land	*Parthenium hysterophorus,Cyperus rotundus*	2.5-6.0 kg.	3.2-7.5	600-1000	20-30 DAS
Diclofop Methyl 28% EC					
Wheat	*Avena fatua, Phalaris minor*	0.7-1.0 kg	2.5-3.5 ltr	500	20-25 DAS
Diuron 80% WP					
Cotton	*Chenopodium album, Convolvulas arvensis Setaria glauca, Digitaria sp, Portulaca oleracea, Xanthium strumerium, Anagallis arvensis, Asphodelus temifolius*	0.75-1.5 kg	1-2.2Kg.	625	1-2 DAS
Sugarcane	*Cyperus iria, Portulaca racea, Echinochloa rusgalli, Cynotis spp, Amaranthus spp, Convonvulus Spp., Digitaria spp.*	1.6-3.2kg	2.0-4.0 kg.	600	Pre emergence
Grapes	*Chenopodium album, Cyperus iria, Euphorbia hirta, Alternanthera echinata, Amaranthus spp, Argemone maxicana, Ipomoea spp,*	1.6kg	2.0 kg.	625	Pre emergence

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	Xanthium strumerium, Fumeria parviflora, Asphodelus tenuifolius				
Flumioxazin 50% SC					
Wheat	*Runnex spp., Medicago denticulate,Coronopus didymus, Chenopodium album, Phalaris minor, Avena fatua*	125 g.a.i/ha	250 ml/ha	500	2-3 DAS
Fluroxypyr meptyl 48% w/v (45.5% w/w) EC					
Onion	*Amaranthus virids, Anagalis arvensis , Chenopodium albumEuphorbia spp. Parthenium hysterophorus, Physalis minimaTrianthema spp.*	324 to 360	675 to 750 ml/ha	600	25-30 DAT
Glyphosate Ammonium Salt 5% SL					
Non Crop area	*Cynodon dactylon Cyprus rotundus Digera arvensis Digitaria sanguinalisEragrostis minor Euphorbia spp. Parthenium hysterophorusTribulus terrestris Xantrhium stremerium*	2 kg.	40 ltrs.	500	Spray only weed as post emergence
Metribuzin 70% WG					
Sugarcane	Sugarcane	Sugarcane	Sugarcane	Sugarcane	25-30DAS
Metsulfuron Methyl 20% WG					
Wheat	*Chenopodium albumMelilotus indioca Melilotus alba Lathyrus aphaca ,Anagalis arvensi,s Vicia sativa, Rumex denticulate, Convolvulus arvensis, Meedicago denticulate*	4 gm.	20 gm.	500-600	30-35 DAS
Oxadiargyl 6% EC					
Cumin	*Cyperus iria, cyperus difformis, Eclipta alba Ludwigia quadrifoliataChenopodium album Remex sp.,Melilotus indica, Asphodelus tenuifolius*	60-75gm	1.0-1.25 ltrs.	500	14-18 DAS
Mustard	*Chenopodium album,Melilotus sp*	90	1500	500	25-30 DAS
Oxyfluorfen 23.5% EC					
Potato	*Chenopodium, Coronpus, Trianthema,Cyperus, Heliotropium*	100-200 gm	425-850	500-750	3-4 DAP
Clodinafop Propargyl 15% + Metsulfuron Methyl 1% WP					
Wheat	*Phalaris minor, Avena fatua, Chenopodiumalbum, Melilotus sp., Fumaria parviflora, Vicia sativa,Rumex sp., Anagallis arvensis, Coronopusdidymus, Lathyrus sp., Convolvulus arvensis*	60+4	400	375 (Add 1250 Ml surfactant	30-35 DAS
Alachlor 50% EC					
Tomato/Brinjal/ Chilli (pre-plant)	*Chenopodium album, Anagalis arvensis,Convolvulus arvensis, Cyperus iria , Portulaca oleracea*	2.0 kg	4 L	250-500	Pre emergence

Precautions in using before herbicide application

This method provides guidelines for determining the optimal time to apply herbicides, taking into consideration factors such as weed growth stage, weather conditions, and specific herbicide characteristics.

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Procedure:

1. Identify the target weed species:
   - Accurately identify the weed species that requires control.
   - Consult weed identification guides or seek expert advice if necessary.
2. Determine the growth stage of the target weed:
   - Different herbicides are most effective at specific growth stages of weeds.
   - Consult herbicide labels or reference materials to identify the growth stage(s) at which the herbicide is recommended.
3. Monitor weather conditions:
   - Weather conditions can significantly impact herbicide effectiveness and potential drift.
   - Consider the following factors:

     a. Temperature: Optimal temperatures for herbicide application vary based on the herbicide. Check the label for specific temperature requirements.

     b. Wind speed: Avoid applying herbicides on windy days to minimize drift. Herbicide labels usually indicate maximum wind speeds for application.

     c. Rainfall: Check the herbicide label for rainfall restrictions both before and after application.
4. Assess the weed population density:
   - Higher weed densities may require earlier herbicide application to prevent competition and yield loss.
   - Consult local agricultural extension services or agronomists for recommendations on threshold weed densities.
5. Consider the crop growth stage:
   - Herbicide application timing should also consider the growth stage of the crop.
   - Some herbicides may have specific crop growth stage restrictions or recommendations. Refer to the herbicide label or crop-specific guidelines.
6. Evaluate herbicide residual activity:
   - Certain herbicides can persist in the soil and affect subsequent crops.
   - Consider rotation restrictions and potential carryover effects when selecting herbicides and determining the application timing.
7. Combine all factors to determine optimal application timing:
   - Take into account the growth stage of the target weed, weather conditions, weed population density, crop growth stage, and herbicide characteristics.
   - Use the information gathered from steps 1-6 to make an informed decision on the best time to apply the herbicide.
8. Follow herbicide label instructions:
   - Read and understand the herbicide label thoroughly before application.
   - Follow all recommended application rates, timing instructions, safety precautions, and any other specific requirements.
9. Document and evaluate results:
   - Record the date, time, weather conditions, and growth stages during herbicide application.
   - Monitor and assess the effectiveness of the herbicide application over time.
   - Use this information to refine future herbicide application timing decisions.

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PRECISION FARMING IN FRUIT CROPS: TECHNOLOGIES, APPLICATIONS, AND FUTURE PROSPECTS FOR SUSTAINABLE HORTICULTURE IN INDIA

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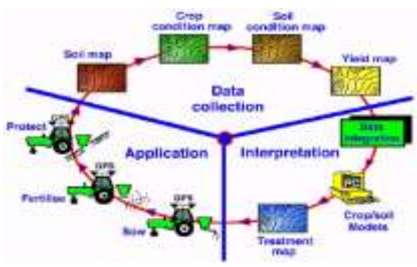
Precision farming has emerged as a transformative approach in modern horticulture, aiming to optimize input use and maximize productivity through the application of advanced technologies. By adopting site-specific management practices, precision horticulture ensures that crops receive the right inputs-such as water, fertilizers, and pesticides-at the right time and in the right quantity. This review explores the fundamental principles, tools, methods, and real-world applications of precision farming in fruit crops. Key components like GPS, GIS, variable rate technology (VRT), remote and proximate sensors, and yield monitoring systems play a crucial role in collecting and analyzing data for improved decision-making. The article also discusses the comparative efficiency of grid and directed sampling methods, the importance of practical applications such as water management and controlled environment agriculture, and the significance of national initiatives like the Tamil Nadu Precision Farming Project. Despite its numerous advantages, including enhanced yield, reduced input costs, and environmental sustainability, the widespread adoption of precision farming in India is challenged by issues such as small landholdings, limited technical awareness, and high initial costs. Nevertheless, the rise of Agri Tech startups is bridging these gaps by delivering innovative solutions tailored to the needs of Indian farmers. This review underscores the potential of precision farming as a sustainable model for the future of fruit crop cultivation in India.

Precision Farming is generally defined as information and technology-based farm management system to identify, analyze and manage spatial and temporal variability within fields for optimum productivity, profitability, sustainability and protection of the land resources by minimizing the production costs. Precision Horticulture, as the name implies, refers to the application of precise and correct amounts of inputs like water, fertilizers, pesticides etc. at the correct time to the crop for increasing its productivity and maximizing its yields. The use of inputs (i.e. chemical fertilizers and pesticides) based on the right quantity, at the right time and in the right place. This type of management is commonly known as "Site-Specific management" Strictly based on Global Positioning System (GPS) i.e. unique character is precise in time and space.

Why is precision farming needed in horticulture?

Precision farming plays a vital role in modern horticulture by enhancing productivity and profitability through site-specific and need-based crop management. It helps prevent soil degradation by promoting sustainable practices that maintain soil health and fertility. One of its key advantages is the significant reduction in the use of chemical inputs, thereby supporting eco-friendly crop production. Furthermore, precision techniques ensure efficient utilization of water resources, which is crucial for regions facing water scarcity. By disseminating advanced farming technologies and practices, precision farming improves both the



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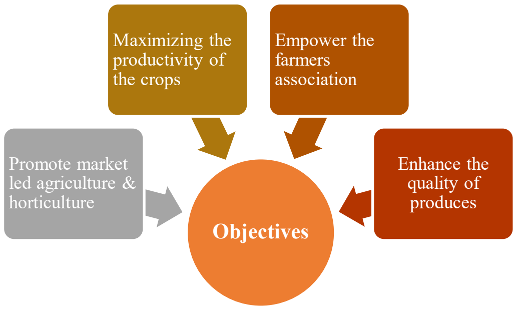
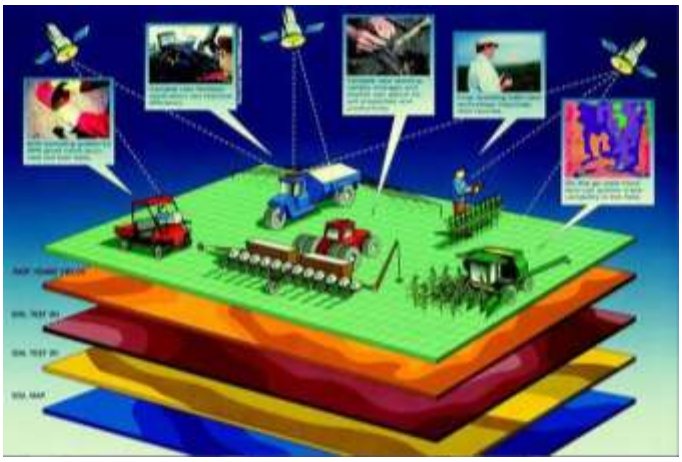
quality and quantity of produce while also reducing the overall cost of production. These benefits collectively make precision farming an essential approach for sustainable and efficient horticultural development.



BASIC PRINCIPLE OF PRECISION FARMING

The process of precision farming begins with sensing key agricultural parameters such as soil moisture, temperature, nutrient levels, and crop health. This is followed by the identification of specific sensing locations within the field and systematic data gathering to capture the variability across different zones. The collected data is then transmitted from the field to a central control station where it is analyzed for informed decision-making. Based on the interpretation of this data, appropriate actions are executed through actuators or automated systems, ensuring timely interventions and optimal resource utilization. This cycle helps in achieving precise control over farming operations, leading to enhanced efficiency, productivity, and sustainability in fruit crop cultivation.



METHODS OF PRECISION FARMING

S.No	PARAMETERS	MAP BASED	SENSOR BASED
1	Methodology	Grid sample, VRA	Real time sensors
2	GPS	Very much required	Not necessary
3	Lab analysis	Required	Not required
4	Mapping	Required	May not required
5	Time consumption	More	Less
6	Limitations	Cost of soil testing and analyses limits the usage	Lack of sufficient sensors for getting crop and soil information
7	Operation	Difficult	Easy
8	Skills	Required	Required
9	Sampling Unit	2 to 3 acres	Individual spot
10	Relevance	Developing countries	Developed countries

TOOLS

GLOBAL POSITIONING SYSTEM (GPS)

A GPS receiver is a location device that calculates its position on earth from radio signals broadcast by satellites orbiting the earth. The U.S. government has 24 satellites that are constantly orbiting the earth. These satellites contain precise atomic clocks, and the exact time is encoded into the signals broadcast from each satellite.

GEOGRAPHIC INFORMATION SYSTEM (GIS)

Geographic information systems (GIS) are computer hardware and software that use feature attributes and location data to produce maps. An important function of an agricultural GIS is to store layers of information, such as yields, soil survey maps, remotely sensed data, crop scouting reports and soil nutrient levels.

GRID SAMPLING

It is a method of breaking a field into grids. Sampling soil within the grids is useful to determine the appropriate rate of application of fertilizers. Several samples are taken from each grid, mixed and sent to the laboratory for analysis. In precision farming, effective soil and crop data collection is essential for site-specific management, and two widely used sampling methods are grid sampling and directed sampling. Grid sampling involves dividing the field into uniform sections or grids and collecting multiple samples from each grid cell to form a composite sample, allowing for a detailed and uniform analysis of soil fertility or crop health across the entire field. In contrast, directed sampling targets specific areas of interest within the field—such as zones showing stress, variability in growth, or historical issues—using GPS to locate and intensively sample these areas, while lightly sampling less critical regions. This method is more efficient in terms of cost and labor when variability is already known. Both techniques play a vital role in generating precise data for informed decision-making and optimizing input usage in modern agriculture.

VARIABLE RATE TECHNOLOGY (VRT)

VRT describes machines that can automatically change their application rates in response to their position. VRT systems are available for applying a variety of substances including granular and liquid fertilizers, pesticides, seed and irrigation water.

YIELD MAPS AND MONITORING

Yield monitor are crop yield measuring devices installed in harvesting equipment. The yield data from the monitor is recorded and stored at regular interval along with positional data received from the GIS unit. GIS software takes the yield data and produce yield map. Mapping of yield and correlation of that map with the spatial and temporal variability of different agronomic parameters helps in development of next season crop management strategy.

REMOTE SENSORS

Remote sensing is tool for data collection, processing and analysis of data to extract information from earth surface without coming into physical contact with it. It holds great promise for precision agriculture because it is potential for monitoring spatial variability over time at high resolution

PROXIMATE SENSORS

These sensors can be used to measure soil parameters such as N status and soil pH and crop properties as the sensor attached tractor or drones passes over the field.

COMPUTER HARDWARE AND SOFTWARE

In order to analyze the data collected by other Precision Agriculture technology components and to make it available in usable formats such as maps, graphs, charts or reports, computer support is essential along with specific software support.

SOFTWARE USED FOR PRECISION FARMING

Precision farming relies on a variety of advanced tools and software platforms to collect, process, and utilize agricultural data effectively. Tools such as Farm Works, SMSTM, and Map shots help in farm planning, record-keeping, and data analysis, enabling

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farmers to make informed decisions. AgDNA, one of the most widely used platforms, integrates data from machinery, sensors, and weather to guide precision practices in real-time. Sentera specializes in drone-based imaging and analytics to monitor crop health and detect early signs of stress. Agrosense offers open-source solutions for data integration, field monitoring, and decision support. These tools collectively enhance the accuracy and efficiency of farm operations, ensuring better yields, reduced input costs, and sustainable management of fruit crops.

PRACTICAL PROBLEMS IN INDIAN HORTICULTURE

Despite its promising benefits, precision farming faces several challenges, particularly in developing countries like India. One of the primary issues is the small and fragmented land holdings, which make the adoption of high-tech solutions economically unfeasible for many farmers. The heterogeneity of cropping systems and market imperfections further complicate uniform implementation. Additionally, there is a lack of technical expertise and awareness among farmers, worsened by low literacy levels and inadequate extension services. India's limited investment in agricultural research and development-only about 0.3% of its agricultural GDP-restricts technological innovation and accessibility. Furthermore, the high initial cost of precision equipment and the poor economic conditions of farmers create financial barriers to adoption. These factors collectively hinder the widespread implementation of precision farming practices, especially in rural and resource-limited settings.

APPLICATIONS

Precision farming finds diverse applications in modern horticulture to ensure efficient and sustainable crop production. One major area is water management, where technologies like drip and sprinkler systems help in delivering water directly to the root zone, minimizing wastage. Surface-covered cultivation, such as the use of mulches, aids in conserving soil moisture and controlling weeds. The implementation of controlled environment structures like greenhouses and polyhouses allows for regulation of temperature, humidity, and light, ensuring year-round cultivation. Precise space utilization through high-density planting and vertical farming techniques helps in maximizing yield per unit area. Furthermore, the integration of Integrated Pest Management (IPM) and Integrated Nutrient Management (INM) ensures balanced and targeted application of inputs, reducing the overuse of chemicals and promoting crop health. These applications collectively enhance productivity, resource efficiency, and sustainability in fruit crop cultivation.

PRECISION FARMING INITIATIVES IN INDIA

Several leading organizations and initiatives have played a vital role in advancing precision farming in India. TATA Kisan Kendra (TKK) has been instrumental in providing farmers with timely agro-advisories, soil testing services, and precision input management. The Tamil Nadu Precision Farming Project (TNPFP), implemented by TNAU and sponsored by the Government of Tamil Nadu, serves as a successful model of adopting high-tech horticulture. The Indian Space Research Organization (ISRO), Ahmedabad, contributes through satellite-based remote sensing and geographic information systems (GIS) to monitor crop health and land use. The M.S. Swaminathan Research Foundation (MSSRF), Chennai, promotes sustainable agricultural practices through technology transfer and farmer training. Additionally, the Project Directorate for Cropping Systems Research (PDCSR) supports research and development in precision-based cropping systems to improve productivity and resource-use efficiency. These institutions collectively contribute to transforming traditional agriculture into a data-driven and efficient system.

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PRECISION FARMING IN TAMIL NADU

The Tamil Nadu Precision Farming Project (TNPFP) is a pioneering initiative sponsored by the Government of Tamil Nadu to promote modern agricultural practices. Implemented as a turn-key consultancy project by the Tamil Nadu Agricultural University (TNAU), the project focuses on enhancing productivity and sustainability through precision farming techniques. With a budget allocation of ₹720 lakhs, the project aims to cover a physical target of 400 hectares in Dharmapuri and Krishna Giri districts. A total of 45 different crops, including both field and horticultural crops, are being cultivated under this initiative. TNPFP serves as a model for integrating scientific approaches in agriculture to increase farmers' income and resource-use efficiency.

ADVANTAGES

Precision farming offers a wide range of advantages that contribute to both environmental sustainability and increased farm profitability. One of its key benefits is the improvement in crop yield by ensuring optimal growing conditions and timely interventions. It provides accurate and real-time information for better management decisions, enabling farmers to respond effectively to field variability. The technology also helps reduce chemical and fertilizer costs through targeted application, minimizing waste and input use. Additionally, it supports accurate farm record-keeping, which is essential for planning, analysis, and compliance. By enhancing efficiency, precision farming increases profit margins while simultaneously reducing environmental pollution, making it a sustainable solution for modern agriculture.

EMERGING AGRITECH STARTUPS IN INDIA

India's agriculture sector is witnessing a technological revolution driven by innovative Agri Tech startups. These startups are leveraging digital tools, AI, IoT, and data analytics to empower farmers and boost productivity. Some prominent names include:

- **Gold Farm** – Focuses on providing farm mechanization services through a digital platform, enabling easy access to rental farm equipment.
- **FASAL** – Offers precision farming solutions using IoT devices and AI to monitor crop conditions and provide actionable insights.
- **CropIn** – A leading AI and data-driven Agri-platform that helps farmers and agribusinesses improve efficiency through smart farm management solutions.
- **AgriCX** – Specializes in providing real-time commodity market intelligence and trading platforms to farmers.
- **Aibono** – Works with precision agriculture and farm analytics to support smallholder farmers with customized crop advisory and yield prediction.
- **Aarav Unmanned Systems** – Uses drones for agricultural surveying, mapping, and data collection to optimize crop management.

These startups are transforming Indian agriculture by introducing smart technologies, improving decision-making, and helping farmers increase income sustainably.

SUCCESS STORY

Precision farming has transformed the lives of many fruit growers across India by enabling efficient resource use and boosting profitability. One such inspiring case is that of Mr. Ravi Patil, a guava farmer from Nashik, Maharashtra, who adopted GPS-based soil testing, moisture sensors, and mobile advisory services. By implementing drip fertigation and real-time monitoring, he reduced input costs by 30% and increased guava yield by 35%, resulting in a 45% rise in income. In Tamil Nadu, under the Tamil Nadu Precision Farming Project (TNPFP), Ms. Lakshmi, a small-scale papaya farmer in Krishna Giri district, installed drip irrigation and followed a sensor-based fertigation schedule. With the guidance of TNAU experts and improved pest management, she saw a 50% increase in fruit quality and doubled her profit within two years. Another successful example is Mr. Harbhajan Singh, a progressive kinnow (mandarin orange) grower in Punjab, who used drone-based spraying, GIS mapping, and remote sensing to optimize orchard management. This approach reduced pesticide use by 40% and improved fruit uniformity, leading to better market prices and enhanced export potential. These stories highlight how precision farming is not limited to large-scale farmers but is also empowering smallholders to achieve sustainability and profitability in fruit crop cultivation.

CONCLUSION

Precision farming represents a smart and sustainable leap forward in the field of fruit crop horticulture. By enabling accurate, data-driven management of agricultural inputs and operations, it helps farmers improve productivity, reduce resource wastage, and protect environmental health. The integration of modern technologies ranging from satellite-based GPS to real-time sensors and AI-driven platforms has revolutionized conventional farming practices, making them more efficient and profitable. Despite facing challenges such as fragmented landholdings, lack of technical literacy, and financial constraints, initiatives like the Tamil Nadu Precision Farming Project and the emergence of forward-thinking Agri Tech startups are paving the way for its wider adoption. To ensure long-term success, increased investment in research, farmer education, and supportive policies will be critical. Precision farming is not just a trend but a necessary evolution for making Indian horticulture more resilient, sustainable, and future-ready.

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Millets: Nutri-Cereals for Health and Climate Resilience

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Millets, referred to as "Nutri-Cereals," are increasingly being appreciated around the world for their function in providing nutrition security, climate resilience, and sustainable agriculture. Announced as the theme for the International Year of Millets 2023 by the UN, millets are rich in nutrition, gluten-free in nature, and useful in disease management, including diabetes and obesity. Their low watering requirements, drought resistance, and capability to grow well in marginal soils make them perfect for climate-resilient agriculture. Millets also enhance soil health and biodiversity, providing a sustainable option against conventional monocultures. At the economic level, millets empower small and marginal farmers with support from policies and increased demand for value-added products. Government programs such as POSHAN Abhiyaan and the PDS are encouraging their large-scale adoption. This bulletin is on the imperative of research, innovation, and value chain development to mainstream millets into modern diets and markets-thereby positing them as true grains of the future

Introduction

The United Nations has announced 2023 as the International Year of Millets (IYM) after the Government of India's proposal, with a view to projecting millets as a strategic crop of international importance for food and nutritional security globally. The recognition highlights the significant role that millets, commonly being called "Nutri-Cereals," play in promoting sustainable agriculture, climate change resilience, and alleviating the acute issues of malnutrition and hunger.

Millets are a group of small-seeded grasses with much diversity being grown in arid and semi-arid tracts of the globe, particularly in Asia and Africa. These ancient cereals sorghum (jowar), pearl millet (bajra), finger millet (ragi), foxtail millet, little millet, kodo millet, barnyard millet, and proso millet are intricately linked with traditional farming systems and cultural traditions. Although they were of great historical significance, millets were preponderantly relegated to the background following green revolution-era policies favoring wheat and rice. But with increasing worries about climate change, water shortage, and lifestyle-related disease outbreaks, millets are now being rediscovered as intelligent foods for the future.

Millets have a number of agronomic strengths: they are resilient crops that need low input, and they can grow in poor soils and under irregular rainfall conditions. Their pest resistance and short cultivation period make them extremely farmer-friendly and sustainable. Nutrition-wise, millets are a health powerhouse high in dietary fiber, proteins, essential amino acids, vitamins (particularly B-complex), and minerals like iron, calcium, and zinc. Their glycemic index is low as well, making them particularly suitable for diabetes and obesity management, hence contributing to all-round well-being.

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Besides nutritional and health advantages, millets play an important role in climate resilience. Their production lessens the reliance on chemical fertilizers and irrigation, which helps in saving natural resources and reducing the carbon footprint. The recovery of cropping systems based on millets presents a way toward attaining the United Nations Sustainable Development Goals (SDGs), specifically those concerning zero hunger, good health, climate action, and sustainable agriculture.

With the world facing food insecurity, environmental degradation, and lifestyle-related diseases, the marketing of millets is a timely and revolutionary opportunity. The International Year of Millets 2023 is a global platform for creating a people's movement to create awareness, mobilize policy action, promote research and innovation, and mainstream millets in food systems and markets. It is a call to action for governments, farmers, researchers, entrepreneurs, and consumers to adopt millets as a foundation of resilient and healthy food systems for the future.

Popular Millets in India

Millet	Common Name	Nutritional Highlight
Pearl Millet	Bajra	High in iron & zinc
Finger Millet	Ragi	Rich in calcium
Foxtail Millet	Kangni	Rich in protein & fiber
Little Millet	Kutki	Antioxidant-rich
Barnyard Millet	Sanwa	Low in carbohydrates
Kodo Millet	Kodo	Good for diabetes
Proso Millet	Chena	Energy-rich
Sorghum	Jowar	Gluten-free

Nutritional Importance of Millets

Millets have come to be known as "Nutri-Cereals" for their remarkable nutritional quality, thus forming an important part of combating undernutrition as well as lifestyle-related health issues. In contrast to traditional cereals like rice and wheat, millets provide a better composition of macronutrients and micronutrients, which are important for good health and overall well-being.

High Contents of Dietary Fiber and Good Quality Proteins

Millets are a rich source of dietary fiber, which facilitates digestion, increases satiety, and promotes the health of the gut. Millets contain proteins with high biological value, rich in essential amino acids that are important for growth and repair of tissues.

Rich in Essential Vitamins and Minerals

Millets are a natural source of B-complex vitamins including niacin, thiamine, and riboflavin, which are essential in energy metabolism and nervous system functioning. They are rich in minerals such as iron, calcium, magnesium, phosphorus, and zinc, which prevent anemia, build bones, and enhance immune function.

Low Glycemic Index:

The slow digestion of complex carbohydrates in millets causes the slow release of glucose into the blood. This low GI rating makes millets extremely useful for diabetic, obese, and cardiovascular patients, as it keeps blood sugar stable and curbs insulin surges.

Gluten-Free and Gut-Friendly:

Millets are gluten-free naturally. Hence, they are safe for consumption by celiac disease patients or people with gluten intolerance. Their non-allergenic and non-acidic nature makes them gentle on the digestive system and reduces inflammation which improves intestine health.

Immunity Booster and Health Promoter

Millets are packed with antioxidants and phytochemicals that promote immune function and fight oxidative stress. Daily intake of millets can prevent deficiency diseases, particularly in children, pregnant women, and lactating women, and thus contribute to long-term health and development.

Climate Resilience of Millets

Millets are becoming increasingly known as climate-smart crops because of their high adaptability to poor environment conditions. Their cultivation helps maintain ecological equilibrium, lowers the carbon footprint of agriculture, and provides a sustainable option in the wake of climate change issues.

Low Water and Input Requirements

Millets are drought-tolerant and do not depend much on chemical fertilizers and pesticides. Their capacity to support crops in dry and semi-dry areas, where traditional crops do not survive, is perfect for rain-fed farming and poor farmer constituencies. This water efficiency is especially important in regions with groundwater loss and uneven rainfall.

Drought, Pest, and Disease Tolerance

In contrast to most climate-resilient staple crops, millets have inherent tolerance to heat, drought, and most pest and disease attacks, thereby lowering the requirements for chemical measures. Their resistance guarantees consistent yields even under climate stress, hence improving farmers' income security and minimizing risks of crop failure.

The majority of millets are ready for harvest in 60 to 90 days, allowing for intercropping and multiple cropping systems the year round. The adaptability enhances crop diversification, maximizes land utilization, and boosts farm productivity in general while minimizing ecosystem pressure.

Soil Health and Carbon Sequestration

Millets help enhance soil fertility and structure due to their vast root systems, which limit erosion and increase organic matter. Millet-based farming systems also help sequester carbon, thus contributing towards alleviating the impacts of global warming and greenhouse emissions.

In effect, millets provide an eco-friendly alternative for input-based agriculture. Their popularization can increase agro-ecosystems' resilience, preserve biodiversity, and make food systems stronger in the face of mounting climate uncertainty.

Millets and Farmer Welfare

Millets not only are good for nutrition and environmental sustainability but also are an effective instrument to enhance the well-being of smallholder and marginal farmers. Their production aligns with low-cost, inclusive, and resilient agricultural systems, offering economic and ecological advantages.

Economic Opportunities to Small and Marginal Farmers

Millets demand low capital outlay, and hence they are suitable for small farmers and resource-poor producers. With increased demand in urban health-oriented markets and government procurement programs, millets provide increased market prospects and stability of income. In addition, their tolerance to climate stress alleviates the risk of crop failure, which is of paramount concern to economically weak producers.

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Promotion of Agro-Biodiversity

Millet cropping accommodates diverse farming systems, preserving traditional landraces and indigenous knowledge. This biodiversity provides ecological balance and agricultural sustainability, particularly against the backdrop of increasing monoculture practices that compromise soil health and enhance pest susceptibility.

Less Mono-Cropping Dependence

By encouraging the adoption of millet-based cropping systems, farmers can break the cycle of dependency on rice and wheat, which are resource-intensive and vulnerable to climate change. This shift also reduces market risks and input costs associated with mono-cropping, leading to greater agricultural resilience.

Enabler of Low-Cost Organic Farming

Millets are also highly adaptable to organic and natural farming as they involve minimal chemical inputs. This allows farmers to easily implement sustainable practices, lower costs of production, and tap into premium organic markets, both domestic and export.

In short, the resurgence of millet production can strongly empower the farmer, particularly in rainfed and marginal regions, through a cost-effective, sustainable, and remunerative farming alternative. Millets promotion is not only a step toward nutrition and climate security but also a strategic action to guarantee economic justice and rural prosperity.

Market & Policy Support

The re-emergence of millets in India is solidly supported by government policies, nutrition programs, and increasing market demand for value-added millet foods. These initiatives are assisting in mainstreaming millets in food systems and increasing their value chain reach from farm to fork.

Inclusion in National Nutrition Missions

Millets are also promoted actively under flagship programs such as POSHAN Abhiyaan (National Nutrition Mission) and the Mid-Day Meal Scheme, with an objective to address malnutrition among women, children, and adolescents. The use of millets in such programs helps in addressing micronutrient deficiency and promotes dietary diversification.

Public Distribution System (PDS)

Various states, like Karnataka, Odisha, Chhattisgarh, and Tamil Nadu, have included millets like ragi, jowar, and bajra in the PDS, making nutritious grains available at affordable prices. Not only does it enhance the food security of low-income groups but also provides assured markets to farmers who grow millets.

Agro-Based Startups and Enterprises Boost

The millet industry is experiencing a boom in entrepreneurship and innovation, especially in the creation of value-added products such as cookies, breakfast flakes, millet noodles, ready-to-eat mixes, health drinks, and energy bars. The products find market among the urban health-conscious consumer and are gaining fast popularity in the home market as well as the export market.

Support by the Government for Processing and Marketing

Under the Millet Mission, National Food Security Mission (NFSM), and Start-up India, the government is facilitating infrastructure for processing, branding, certification, and marketing of millets. Financial support, capacity-building activities, and research grants are also being made available to encourage millet-based businesses.

Way Forward

In order to maximize the utilization of millets to ensure food security, nutrition, and climate resilience, there needs to be a multi-dimensional and participatory way. The way forward could be through the following strategies that can lead to a millet-led revolution in agriculture and food systems:

Facilitate Research and Extension Services

Investing in research on high-yielding, climate-resilient millet varieties and better agronomy will be vital. Organizing agricultural extension services will facilitate timely delivery of these innovations to farmers, particularly in millet-producing areas.

Make Millets Mainstream in Modern Diets

Promotion campaigns and food innovations will be able to re-create millet recipes that are more appealing to contemporary palates. Inclusion in restaurants, cafeterias, and food retail chains, and nutrition labeling and branding, will increase the consumer acceptability and demand.

Strengthen Value Chains and Market Linkages

It requires the creation of strong value chains—from production and processing to packaging and marketing. These are the cold storage, milling, grading, e-commerce platforms, and export facilitation, particularly for millet-based MSMEs and startups.

Promote Climate-Smart Agricultural Practices

Propagation of millets in climate-resilient cropping systems, particularly rainfed and marginal ones, can counter climate change effects. Encouraging millet cultivation with green subsidies, insurance programs, and carbon credit schemes can also increase adoption.

Conclusion

Millets are not only old grains they are future grains, able to revolutionize the face of food and agriculture. Their nutritional density, environmental resilience, and economic potential make them the real superfoods of the 21st century.

By adopting millets, we make a strong move toward fulfilling nutrition security, environmental sustainability, and rural prosperity. Under the threat of global challenges like malnutrition, water shortages, and climate change, millets provide a resilient, inclusive, and sustainable way forward for producers and consumers alike.

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Organic vs. Conventional Farming: A Comparative Insight

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Introduction

Agriculture, the pillar of human civilization, has witnessed extraordinary changes over the course of centuries. In the last few decades, two prevailing methodologies have been at the center of worldwide agricultural thought: Organic Farming and Conventional Farming. Each methodology is a unique philosophy, a set of practices, and an idea about the future of food production. Organic farming involves the use of natural inputs, biological processes, and agroecological principles. Organic farming aims to preserve soil fertility, encourage biodiversity, and minimize reliance on synthetic chemicals. Crop rotation, composting, green manuring, and biological control of pests are some of the techniques that are an essential part of organic systems. Organic farming aims to establish a symbiotic relationship between agriculture and nature so that it lasts for generations and provides safe food.

Contrarily, Conventional farming, also referred to as industrial or modern agriculture, depends extensively on synthetic fertilizers, chemical pesticides, high-yielding crop varieties, and mechanized equipment in order to maximize production. This approach has been pivotal in attaining food security, particularly during the Green Revolution and subsequent years, by significantly producing more crops and alleviating hunger in a majority of parts of the world.

But both systems also have drawbacks. Organic farming is highly valued for its health and environmental advantages but also faulted for reduced productivity and higher prices. Conventional farming, which is more productive in the short run, is said to have soil degradation, water pollution, residues from chemicals, and loss of biodiversity.

This bulletin seeks to give an intensive comparison of conventional and organic farm systems. Their performance in important aspects like sustainability, productivity, environmental effects, economic profitability, and human health is assessed. It is important for farmers, policymakers, researchers, and consumers to know these differences as they navigate the intricate issues of securing food while protecting the planet for generations to come.

Comparative Analysis

Feature	Organic Farming	Conventional Farming
Inputs	Natural, organic	Synthetic, chemical
Soil Health	Improves soil structure and microbial activity	Often degrades soil with long-term use
Yield	Moderate but stable	High but sometimes unsustainable
Cost of Production	Initially high, but sustainable	Lower initially but increasing over time
Environmental	Eco-friendly,	Pollution,

Impact	low emissions	biodiversity loss
Health Impact	Reduces chemical residues in food	May contain pesticide residues
Certification & Market	Premium pricing in niche markets	Standard market pricing

What is Organic Farming?

Organic farming is a sustainable and environmentally friendly method of cultivation that focuses on the utilization of natural processes and materials to grow crops and raise animals. In contrast to conventional farming, organic farming shuns the use of synthetic chemical fertilizers, pesticides, genetically modified organisms (GMOs), and growth regulators. Organic farming uses traditional agricultural methods that increase soil fertility, enhance biodiversity, and preserve ecological equilibrium instead.

One of the key components of organic farming is the use of organic manures, such as farmyard manure (FYM), compost, and green manure, which enrich the soil with essential nutrients and improve its structure and water-holding capacity. These natural amendments help maintain soil fertility without the negative side effects associated with synthetic fertilizers.

Biological control of pests is also an essential part, where good insects, predators, and natural deterrents are employed to bring pest populations under control, minimizing the usage of chemical pesticides and maintaining the health of the agroecosystem.

Organic farming also utilizes crop rotation and intercropping strategies, which shatter pest and disease cycles, enhance soil health, and maximize the efficiency of land and resources. They help to ensure that the same nutrients are not persistently extracted from the soil, hence ensuring long-term productivity.

Besides, organic agriculture utilizes a great deal of biofertilizers like Rhizobium, Azospirillum, Azotobacter, and phosphate-solubilizing bacteria, which increase the availability of nutrients through biological fixation. These microbial inoculants promote the growth of plants naturally and in a sustainable manner.

In addition, traditional practices and indigenous knowledge systems are the foundation of organic agriculture. Some examples include locally evolved seed varieties, weather forecasting using ecological indicators, and traditional forms of natural farming practiced over generations, which tend to be more resilient as well as adapted to local conditions. In general, organic agriculture seeks not only to grow food, but to do so in a manner that is ecologically sound, socially just, and economically sustainable in the long run.

What is Conventional Farming or Industrial Agriculture?

Conventional farming or industrial agriculture or modern agriculture is a prevailing farming practice aimed at maximizing crop productivity and efficiency by applying new technologies and synthetic inputs. This type of agriculture has been instrumental in increasing food production, particularly since the Green Revolution, and has heavily contributed to nourishing the increasing world population.

One of the main features of traditional agriculture is the intensive application of chemical pesticides and synthetic fertilizers. These products are formulated to deliver nutrients rapidly to crops and fend them off from pests, weeds, and diseases. They indeed play a role in increasing the yield in the short term, but excessive use has become a source of worry regarding soil deterioration, water contamination, and health hazards owing to residues from chemicals.

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Another characteristic of this system is the use of hybrid seeds and genetically modified organisms (GMOs), which are selectively bred or designed for characteristics such as high production, resistance to pests, and tolerance to drought. These seeds tend to be uniform in character, resulting in greater productivity but also depriving crops of genetic diversity.

Traditional agriculture typically utilizes monoculture cropping systems, in which one crop is cultivated season after season across vast areas of land. It makes farming simpler and enhances short-term production but can heighten susceptibility to pests, diseases, and nutrient losses, tending to require even more extensive use of agrochemicals.

Further, tillage with machines and sophisticated irrigation systems form the core of the traditional method of farming. Tractors, harvesters, and irrigation systems make the use of labor more efficient and enable extensive farming operations. Ongoing tillage can damage soil health, and incorrect irrigation methods can produce waterlogging or salinization.

In effect, traditional farming emphasizes productivity and profitability, frequently at the cost of long-term environmental sustainability. Although it has succeeded in fulfilling demand for food, more need now arises to balance its advantages against more sustainable measures so that future generations will have food security.

Environmental and Health Impacts

The organic versus conventional production decision has important implications for the environment and human health. Both systems impact soil quality, biodiversity, water supplies, air pollution, and food safety differently.

Organic agriculture tends to be more environmentally friendly. By excluding synthetic fertilizers and chemical pesticides, it works to maintain soil fertility, minimize pollution, and safeguard useful organisms like earthworms, pollinators, and soil microbes. Organic methods such as composting, cover cropping, and agroforestry enhance carbon sequestration, which contributes to the reduction of climate change by trapping atmospheric carbon in soils. Organic farms are also likely to have higher biodiversity levels, providing shelter for a variety of plant and animal species. From a health standpoint, organic foods do not contain dangerous chemical residues, thus making it safer for people to consume, particularly children and those who are vulnerable.

At the same time, traditional farming albeit effective in the production of large quantities of food—is associated with a number of negative environmental and health impacts. Overuse of chemical fertilizers and pesticides can lead to pollution of groundwater, impacting the quality of drinking water and aquatic life. Monoculture and chemical addiction tend to cause resistance on the part of pests, necessitating application of even more potent or more frequent chemicals, which further degrade the environment. In addition, the extensive consumption of fossil fuels to perform mechanization and the manufacture of agrochemicals results in greenhouse gases, hence hastening global warming. From a health perspective, traditional farming can subject farmers and consumers to poisonous residues that result in long-term health effects such as hormonal interference, respiratory issues, and other chronic diseases.

In short, although both systems will feed the population, they have very different long-term impacts on the environment and health. Organic farming is more in line with ecological harmony and public health, while conventional farming needs strategic adjustments to mitigate its environmental impact.

Economic Considerations

The financial feasibility of organic and conventional agricultural systems differs substantially depending on such factors as costs of inputs, levels of yields, access to markets, and market demand.

Organic production, even with generally lower crop yields, remains economically feasible owing to the premium prices that organic commodities attract in the marketplace. Econsumers are becoming more and more willing to pay a premium for food that is free of synthetic chemicals and produced with environmentally friendly practices. This premium price will be able to mitigate the increased labor costs and lower productivity of organic farming. Organic farming also reduces dependence on costly external inputs like chemical fertilizers and pesticides, which will decrease the cost of production overall over the long term. With good market linkages, certification, and value addition, organic agriculture can be both sustainable and profitable, particularly for marginal and small farmers.

Conventional agriculture, on the other hand, takes advantage of economies of scale, enabling largescale operations to produce food at comparatively cheap per-unit price. Mechanization, high-yielding varieties, and agrochemical inputs contribute to higher productivity and faster turnaround times. But this structure is increasingly exposed to increasing input prices, such as the rising costs of fertilizers, pesticides, fuel, and hybrid seeds. In addition, price volatility for traditional fruits and vegetables can impact farmers' revenues significantly, especially if supply outweighs demand. Reliance on external inputs and unstable markets tends to lead to financial insecurity, particularly for smallholder farmers.

Research Insights

Various national and international studies have highlighted the performance and potential of organic and conventional farming systems. The findings of bodies like the Food and Agriculture Organization (FAO), Indian Council of Agricultural Research (ICAR), and the International Federation of Organic Agriculture Movements (IFOAM) identify comparative advantages of organic agriculture in more than one dimension.

According to long-term studies, organic farming can achieve yields comparable to conventional systems, particularly under rainfed and low-input conditions. With proper soil management, crop diversity, and organic inputs, organic farms can sustain productivity over time while reducing environmental stress.

Evidence also indicates that organic foods tend to have greater levels of certain vitamins, most notably antioxidants, vitamin C, and polyphenols, than traditionally produced food. This is because plants are grown more slowly and without synthetic inputs, which make them produce more defensive phytochemicals.

In addition, soil health is significantly enhanced in organic systems. Soil organic matter, structure, and microbial activity are enhanced through practices like the application of compost, crop rotation, and the adoption of cover crops. These enhancements result in increased water retention, erosion reduction, and enhanced resilience to climate variability. These advantages, in turn, contribute to sustainable use of the land and decreased reliance on synthetic inputs in the long term.

All in all, studies validate the observation that organic production, although more labor- and knowledge-heavy at first, can provide long-term environmental and nutritional benefits without sacrificing significantly on yield when properly done.

Way Forward

With global agriculture challenged by the need to ensure food security and protect environmental health at the same time, there is an increasing imperative to break past the binary of conventional and organic farming. An integrated and comprehensive approach that merges the best qualities of both systems holds the promise of a more resilient and sustainable food system.

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One of the hopeful avenues is the implementation of integrated farming techniques that combine the ecological practices of organic agriculture with the efficiency of today's technologies employed in mainstream agriculture. INM and IPM methods can minimize the use of chemicals while sustaining productivity.

For making organic agriculture a more attractive proposition, capacity building is required by way of training farmers. Farmers must have access to information on organic methods, soil health management, pest management, and organic certification procedures. Government subsidies, economic incentives, and facilitating certification mechanisms can also encourage farmers to shift to or increase organic agriculture.

As crucial is consumer education and awareness. Building public knowledge of the health and environmental advantages of organically produced food can stimulate demand and build the organic marketplace. This involves encouraging eco-labeling, farmers' markets, and direct-to-consumer channels that link producers and mindful consumers.

In summary, the future of farming is synergy, not separation. Through synergizing sustainable practices from organic and conventional systems, and through empowering farmers and consumers as well, we can create a productive, profitable, and sustainable farm landscape.

Conclusion

Both conventional and organic farming systems have their respective strengths and weaknesses. Organic farming is most prized for being an environmental steward, conserving biodiversity, and delivering health-friendly crops, while the conventional system has played a crucial role in realizing large-scale food production and solving global hunger.

Still, with increasing concerns regarding climate change, soil erosion, water stress, and food safety, it is evident that neither system by itself can solve all of the problems of contemporary agriculture. The solution in this case is sustainable intensification—a strategy that aims to enhance agricultural productivity while, at the same time, conserving the environment and promoting social and human well-being.

Through the application of each system's best practices, stimulating innovation, and fostering policy for sustainable agriculture, we can develop a food system that is strong enough to support current and future generations. Farmers, researchers, policymakers, and consumers will be most important in attaining this balance between productivity and sustainability.

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Zeolite: Nature's Molecular Sieve for Sustainable Agriculture and Environmental Protection

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Zeolites are crystalline, microporous minerals known for their remarkable ion-exchange and adsorption properties. With a robust aluminosilicate framework and high surface area, they offer sustainable solutions across various fields—from agriculture to wastewater treatment and petrochemicals. This article explores the structural characteristics, classifications, and diverse industrial and environmental applications of zeolites. It highlights their transformative role in agriculture, including improved fertilizer efficiency, soil conditioning, heavy metal remediation, and enhanced crop productivity. Given their non-toxic nature and high availability, zeolites represent a promising tool in addressing the limitations of conventional fertilizers and promoting ecological balance.

Introduction

Zeolites, often described as "nature's molecular sieves," are crystalline aluminosilicates with a unique porous structure that allows them to selectively adsorb molecules based on size and polarity. These minerals, occurring naturally in volcanic rocks or synthesized in laboratories, are prized for their ion-exchange capacity, catalytic properties, and thermal stability. Their growing importance in sustainable agriculture, environmental remediation, and industrial processes is driven by the need to reduce dependence on synthetic chemicals, improve soil health, and mitigate environmental degradation.

As modern agricultural practices become increasingly reliant on synthetic fertilizers, the limitations of such inputs—nutrient loss, heavy metal accumulation, soil salinization, and greenhouse gas emissions—have become pressing concerns. Zeolites offer a sustainable alternative, enhancing nutrient efficiency while minimizing environmental harm. This article delves into the structural framework of zeolites, their classification based on pore size and composition, and their extensive applications in environmental management and agriculture.

Structure and Classification of Zeolites

Zeolites consist of a three-dimensional framework built from silicon-oxygen (SiO_4) and aluminum-oxygen (AlO_4) tetrahedra. These tetrahedra form a negatively charged matrix that is balanced by exchangeable cations such as sodium, calcium, or potassium. This ion-exchange capability is central to many zeolite applications, including water purification, agriculture, and catalysis.

Zeolites are broadly categorized into two types:

- Natural Zeolites (e.g., clinoptilolite, mordenite, chabazite): Found in volcanic and sedimentary environments.
- Synthetic Zeolites (e.g., zeolite A, X, Y, ZSM-5): Manufactured for uniform pore sizes and high chemical purity.

One key feature influencing zeolite behaviour is the silicon-to-aluminum (Si/Al) ratio (Ramesh *et al.*, 2010):

- High-silica zeolites (e.g., erionite): Si/Al > 10; suitable for organic adsorption.
- Intermediate-silica zeolites (e.g., zeolite Y): Si/Al = 2–5.

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- Low-silica zeolites (e.g., zeolite A): Si/Al = 1–1.5; ideal for water adsorption.

A pore-size-based classification introduced by Jacobs *et al.* (2001) further refined zeolite types:

- Extra-large pores: 14-membered rings, 0.8–1.0 nm
- Large pores: 12-membered rings, 0.6–0.8 nm
- Medium pores: 10-membered rings, 0.45–0.6 nm
- Small pores: 8-membered rings, 0.3–0.45 nm

This classification helps match specific zeolite types with industrial or agricultural needs.

Environmental Concerns with Synthetic Fertilizers

Synthetic fertilizers have revolutionized modern agriculture but brought serious ecological consequences. Globally, the overuse of nitrogen and phosphorus fertilizers contributes to ammonia (NH_3) volatilization, eutrophication, soil degradation, and nitrous oxide (N_2O) emissions (Pan *et al.*, 2016)—a greenhouse gas with 300 times the warming potential of CO_2.

Pic1: Zeolite Molecular Sieves

In coastal regions, combining saline irrigation with chemical fertilizers accelerates soil salinization and disrupts microbial ecosystems. Additionally, synthetic fertilizers often contain heavy metals (e.g., Cd, Pb, As) and radioactive isotopes (e.g., U-238), which accumulate in soils and crops, posing human and ecological health risks. These inputs, if not managed carefully, lead to runoff, leaching, and declining soil fertility—threatening long-term agricultural sustainability.

Applications of Zeolites

1. Water Purification and Softening

Zeolites remove hardness ions (Ca^{2+}, Mg^{2+}), heavy metals, and radioactive substances from water. Their ion-exchange properties are critical in municipal and industrial wastewater treatment.

2. Agriculture

Zeolites serve as soil conditioners and slow-release fertilizer carriers. They enhance nutrient retention, improve water holding capacity, and increase crop productivity.

3. Petrochemical Industry

Synthetic zeolites are essential catalysts in fluid catalytic cracking (FCC), converting heavy hydrocarbons into gasoline and diesel.

4. Detergents

Zeolite A has replaced phosphates in many detergents, reducing eutrophication while maintaining washing performance.

5. Medical Uses

Clinoptilolite is used in detox supplements and wound care. Its microporous nature allows it to adsorb toxins and promote healing.

6. Gas Separation and Storage

Zeolites can selectively capture gases like CO_2 and CH_4, offering solutions for carbon capture and hydrogen storage.

Zeolites in Agriculture

1. Fertilizer Efficiency

Zeolites improve nutrient availability by capturing and slowly releasing nitrogen and potassium. This minimizes leaching, increases fertilizer efficiency, and reduces costs. Studies show improved yields in crops such as maize and spinach.

2. Soil Conditioning

By enhancing cation exchange capacity and moisture retention, zeolites improve soil structure and microbial activity. Their alkaline nature also helps neutralize acidic soils, enhancing crop growth in arid and semi-arid zones.

3. Controlled Agrochemical Release

Zeolites act as carriers for herbicides and pesticides, enabling controlled release and reducing environmental pollution. Research has demonstrated reduced leaching of chemicals like atrazine and paraquat when combined with zeolite.

4. Heavy Metal and Radionuclide Immobilization

Zeolites bind toxic metals like lead and cadmium, preventing their uptake by plants. They are particularly effective in rehabilitating contaminated lands and mitigating radioactive contamination.

5. Water-Use Efficiency

Zeolites absorb up to 60% of their weight in water, making them valuable in drought-prone areas. In crops like rice and beans, their use reduces irrigation needs while improving yields.

6. Livestock and Odor Management

Zeolites absorb ammonia and hydrogen sulphide, reducing Odors in livestock environments. When added to bedding or compost, they cut emissions and improve waste quality.

7. Crop Protection and Photosynthesis

Zeolite sprays act as barriers against pests and fungi. They may also enhance photosynthesis by increasing CO_2 levels near leaf surfaces, improving productivity in crops like tomatoes and grapes.

8. Aquaculture and Animal Nutrition

In aquaculture, zeolites regulate ammonia and improve water quality. As feed additives, they bind toxins and improve nutrient absorption in livestock and poultry (Cataldo *et al.*, 2021).

Conclusion

Zeolites offer a powerful and sustainable alternative to many conventional agricultural and industrial inputs. Their ability to adsorb, exchange, and retain ions makes them versatile agents in water purification, soil improvement, gas separation, and environmental remediation. Particularly in agriculture, zeolites address key concerns such as nutrient leaching, heavy metal contamination, and water scarcity—making them indispensable for future-ready farming. As environmental pressures mount and sustainability becomes non-negotiable, zeolites stand out as a natural, effective, and economically viable solution to enhance productivity while protecting ecosystems.

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Arborsculpture: The Art and Science of Shaping Living Trees

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Introduction

Arborsculpture is a unique blend of art, horticulture, and design that involves training and shaping living trees into artistic or functional structures. Also known as tree sculpting or botanical architecture, this technique uses grafting, pruning, bending, and other plant training methods to guide the natural growth of trees into desired forms. It is both an environmentally friendly practice and a long-term art form that requires patience, creativity, and a deep understanding of plant biology.

History and Origins

The roots of arborsculpture go back centuries. Indigenous cultures and early civilizations have practiced simple forms of tree shaping. In India, for example, people constructed "living root bridges" using the aerial roots of rubber trees. In Europe, the concept of *pleaching*—interweaving tree branches—was used in gardens and orchards. However, modern arborsculpture as an artistic and architectural pursuit was popularized in the 20th century by practitioners like Axel Erlandson, who created the famous “Tree Circus” with trees shaped into spirals, loops, and hearts.

Techniques Used in Arborsculpture

Arborsculpture involves several horticultural techniques that work with the natural tendencies of tree growth:

- **Grafting**: This is the most essential technique, where two or more parts of the same or different trees are joined so they grow as one. This allows branches or trunks to be fused in specific patterns.
- **Pruning and Pinching**: Regular trimming helps control growth direction, remove unwanted branches, and shape the tree over time.
- **Bracing and Bending**: Frames, molds, or guides are used to bend trunks and branches into certain angles or curves as they grow.
- **Training**: Young and flexible saplings are trained early on to grow in predetermined directions. This long-term process may take years but results in strong and healthy structures.

Popular Designs and Structures

Artists and practitioners have created a wide range of arborsculptures. These include:

- **Furniture**: Living chairs, tables, and benches shaped from tree trunks.
- **Sculptures**: Artistic patterns like spirals, knots, cages, and human figures.
- **Structures**: Arbors, gazebos, fences, and even houses made from living tree trunks and branches.

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Some designs are purely decorative, while others serve a functional or architectural purpose, merging art with sustainability.

Tree Species Suitable for Arborsculpture

Not all trees are suitable for arborsculpture. The ideal species should be fast-growing, flexible when young, and capable of grafting. Commonly used species include:

- **Willow (*Salix* spp.)** – Fast-growing and highly pliable.
- **Sycamore (*Platanus* spp.)** – Grafts easily and grows quickly.
- **Box Elder (*Acer negundo*)** – Softwood and good for bending.
- **Elm (*Ulmus* spp.)** – Resilient and easy to shape.

Benefits of Arborsculpture

Arborsculpture is more than just artistic expression—it offers several practical and ecological benefits:

- **Eco-Friendly Architecture**: Living structures reduce the need for processed materials like concrete or steel.
- **Carbon Sequestration**: Trees absorb carbon dioxide, helping combat climate change.
- **Aesthetic Appeal**: Shaped trees can enhance public spaces, parks, and private gardens.
- **Biodiversity**: These structures provide habitats for birds, insects, and other wildlife.
- **Educational Value**: Arborsculpture projects can teach biology, sustainability, and patience to students and hobbyists.

Challenges and Considerations

While arborsculpture is rewarding, it also comes with challenges:

- **Time**: It may take several years, even decades, to achieve complex designs.
- **Maintenance**: Regular care, pruning, and training are essential to maintain form and tree health.
- **Skill and Knowledge**: Practitioners need to understand grafting techniques, tree physiology, and long-term plant care.
- **Environmental Factors**: Storms, droughts, pests, or diseases can damage the structure if not properly managed.

Modern Applications and Innovations

Arborsculpture is being explored not just by artists, but also by eco-architects and green design enthusiasts. Some projects envision **living homes** or **bridges** that grow and evolve over time. Innovations like computer-aided design (CAD) and drone monitoring are being incorporated into the planning and maintenance of complex living structures. Public gardens and ecological installations around the world now feature arborsculpture as a central attraction.

Conclusion

Arborsculpture stands at the intersection of nature and human creativity. It encourages us to slow down and interact with living organisms in meaningful, artistic ways. As a sustainable form of art and architecture, it promotes harmony with nature and showcases the incredible potential of patient, long-term design. Whether for personal enjoyment or public display, arborsculpture inspires a greener and more imaginative future.

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Bridging Climate Knowledge Gaps: A Participatory Media Approach to Sustainable Agriculture Among Tribal Communities in HD Kote

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In Karnataka's HD Kote taluk—home to indigenous communities such as the Jenu Kurubas—the adoption of climate-smart agricultural practices remains limited despite targeted institutional efforts. This study explores the potential of integrating community-owned media platforms, particularly community radio, with citizen science reporting to bridge knowledge gaps, enhance agro-climatic risk awareness, and promote sustainable farming. The research introduces a participatory radio–citizen science model wherein tribal farmers serve as active contributors by submitting audio-based agro-observations. These community-generated reports are broadcast via local radio stations, offering localized advisories in native dialects.

A mixed-methods approach was adopted, comprising participatory action research, capacity-building of tribal youth as citizen-reporters, and a pilot implementation in Basavanagiri Haadi and Sollepura villages. Data were collected through interviews, media content logs, and adoption surveys. Quantitative analysis indicated a 22% increase in the uptake of climate-resilient practices and a 30% rise in farmer engagement with community radio. This study presents a scalable, media-integrated agricultural extension framework aimed at empowering tribal communities and reinforcing grassroots-level communication systems in climate adaptation strategies.

Introduction

India's tribal communities constitute approximately 8.6% of the national population, with the majority residing in forested or ecologically sensitive regions where agriculture remains a primary livelihood source (Census of India, 2011). Despite their deep-rooted ecological knowledge and reliance on natural resources, these communities remain systematically excluded from mainstream agricultural development frameworks. Their marginalization is particularly pronounced in the context of climate-smart agriculture (CSA), where modern interventions often fail to reach, resonate with, or benefit tribal populations due to socio-cultural, infrastructural, and linguistic barriers (Rao et al., 2018).

HD Kote taluk, located in Mysuru district of Karnataka, exemplifies these challenges. With a high concentration of Jenu Kuruba and other tribal groups who primarily depend on subsistence farming and forest-based livelihoods, the region is highly vulnerable to climate variability, soil degradation, and erratic rainfall patterns. Although institutions such as the Indian Council of Agricultural Research (ICAR)-University of Agricultural Sciences (UAS), Bangalore, and grassroots NGOs like Sahaja Samrudha have introduced several climate-resilient agricultural schemes in the region, the uptake among tribal farmers has remained limited. Factors contributing to this limited adoption include the lack of access to context-sensitive information, poor last-mile connectivity, and the absence of culturally appropriate knowledge dissemination platforms (Sreedharan et al., 2021).

Agricultural extension systems in India, historically structured around top-down models, often overlook the lived realities, linguistic diversity, and local knowledge systems of indigenous communities. As a result, communication becomes a bottleneck in the technology adoption process. This paper responds to this critical gap by proposing a participatory media model that leverages community radio and citizen science reporting to create a culturally responsive, decentralized, and inclusive agricultural communication framework for tribal regions.

Community radio—defined by UNESCO as a "third-tier" media platform owned and operated by communities—is particularly suited for rural communication due to its accessibility, hyperlocal focus, and capacity for broadcasting in local dialects (UNESCO, 2014). Similarly, citizen science, which involves non-professionals in the co-creation of scientific knowledge, has gained momentum as a democratic knowledge production method in environmental monitoring and agriculture (Bonney et al., 2016). Combining these two approaches can create a robust grassroots communication infrastructure where tribal farmers are not just recipients but active co-creators of agricultural information.

This study specifically explores the deployment of a radio–citizen science integration model in two tribal villages—Basavanagiri Haadi and Sollepura—in HD Kote. Through participatory action research (PAR), tribal youth were trained as citizen-reporters to record and share observations related to soil, crop conditions, rainfall patterns, and pest outbreaks. These audio reports were curated and broadcast through local community radio channels in local dialects, accompanied by expert advisories and farmer-to-farmer learning segments.

The central hypothesis of this paper is that bottom-up, media-integrated communication models can significantly enhance the uptake of climate-resilient practices by making agricultural information more accessible, relatable, and timely. By empowering tribal communities to participate in both the production and dissemination of knowledge, this study aims to contribute a scalable and culturally embedded model of agricultural extension suited to India's tribal heartlands.

2. Literature Review

Tribal farmers in India and other developing regions often face entrenched systemic challenges that hinder agricultural development. These challenges include linguistic exclusion, limited access to reliable agricultural information, geographic isolation, and minimal engagement with formal agricultural advisory systems (Meera et al., 2004). Research indicates that mainstream agricultural extension models frequently fail to accommodate the socio-cultural diversity and communication needs of tribal populations Language barriers and the absence of culturally resonant communication tools further marginalize these communities from scientific knowledge dissemination.

Community media, especially community radio, has emerged as a powerful platform to bridge these communication gaps. Fraser and Restrepo Estrada (2002) emphasized the role of community radio in promoting inclusive communication by ensuring that the voices of marginalized communities are both heard and respected. Unlike commercial or national media, community radio enables localized content creation, encourages listener participation, and supports linguistically and culturally appropriate messaging. In tribal regions, radio can overcome barriers such as illiteracy and geographic remoteness, making it a particularly effective medium for disseminating agricultural knowledge, weather forecasts, pest management practices, and market updates

Parallel to this, citizen science has gained recognition as a participatory approach that engages non-scientists in data collection, monitoring, and knowledge production—especially in fields like ecology, agriculture, and environmental management. Bonney et al. (2014) outlined how citizen science contributes not only to data collection but also to empowering local communities to influence policies and practices affecting their environments. In tribal areas, such participatory methods can democratize scientific engagement, promote local knowledge integration, and build community ownership of scientific processes.

Despite the individual merits of community media and citizen science, their synergistic potential in the domain of tribal agriculture remains significantly underexplored. There is a noticeable gap in literature when it comes to integrating community-driven communication tools with participatory scientific methods to address the unique agricultural needs of tribal farmers. The potential of combining community radio broadcasting with citizen science approaches—for example, by enabling farmers to share local observations about crop health, rainfall patterns, or soil conditions over the radio—has not been sufficiently studied or piloted in the Indian context.

Studies that touch upon this intersection highlight promising but isolated examples. For instance, projects in parts of Sub-Saharan Africa have used community radio to report citizen-collected climate data (Roncoli et al., 2009), demonstrating the feasibility of such integrated models. Yet in India, and particularly in tribal regions, such cross-pollination of community media and citizen science remains a fertile ground for innovation, research, and development.

3. Research Objectives

- To develop a participatory communication model using community radio and citizen-science.
- To evaluate its impact on awareness, behavior, and adoption of climate-smart practices among tribal farmers.
- To assess its scalability and replicability across similar tribal contexts in India.

4. Methodology

This study employed a mixed-methods approach, combining qualitative and quantitative techniques to ensure a comprehensive understanding of participatory communication and its influence on climate-smart agricultural practices among tribal communities. The research was carried out over five structured phases in the HD Kote region of Karnataka, India, focusing on two tribal villages: Basavanagiri Haadi and Sollepura.

Phase I: Participatory Action Research (PAR) and Stakeholder Mapping

In the initial phase, Participatory Action Research (PAR) was employed to actively engage with the local tribal communities, including farmers, youth, local leaders, NGOs, and agricultural extension officers. Stakeholder mapping was conducted to identify key individuals and institutions influencing agricultural decisions and climate adaptation in the region.

- **Outputs:** Community needs assessments, communication ecosystem mapping, and identification of trusted local media channels (especially community radio).

Phase II: Capacity Building of Tribal Youth in Mobile Audio Reporting

The second phase involved conducting **training workshops for tribal youth aged 18–25**, focusing on:

- Mobile journalism using smartphones
- Basics of audio recording and editing
- Field documentation of agricultural and environmental issues

The workshops incorporated **hands-on learning modules** and were facilitated in collaboration with media trainers and agricultural extension workers.

Phase III: Pilot Implementation in Basavanagiri Haadi and Sollepura

A pilot program was launched in the selected villages where trained youth produced weekly audio reports on local agro-climatic issues, including:

- Pest outbreaks
- Rainfall variability
- Soil health and erosion concerns

These reports were gathered via smartphones and uploaded through digital platforms or physically transferred to the partner radio station.

- **Tools Used:** Open-source mobile apps (like Voice Recorder, Audacity, and Ona Mobile) and basic documentation templates.

Phase IV: Community Radio Broadcasts

The audio content was edited, curated, and broadcast through **Radio Nagarika (Mysuru)**, a licensed community radio station operating in the region. The content was delivered in **local dialects**, ensuring cultural relevance and better comprehension.

- **Broadcast Frequency:** Weekly 30-minute slots per village, supplemented by expert commentary from agricultural officers and scientists.
- **Justification:** Community radio has proven effectiveness in enhancing agricultural communication in rural India (UNESCO, 2021, Kumar, 2014).

Phase V: Evaluation and Impact Assessment

To assess the effectiveness of the intervention, a mixed-methods evaluation was conducted:

- **Pre- and post-intervention surveys** (n = 120) to measure changes in awareness, attitudes, and adoption of climate-resilient practices.
- **Focus Group Discussions (FGDs)** with farmers, youth reporters, and local leaders to capture qualitative insights.
- **Radio Analytics** including listener feedback, call-ins, and engagement logs.
- **Evaluation Indicators:**
  - Awareness of pest control techniques and weather patterns
  - Behavioral change in farming practices
  - Community engagement with radio broadcasts
- **Justification:** Triangulation enhances validity and provides richer insights (Creswell & Plano Clark, 2018).

Summary of Methodological Strengths:

- Combines participatory development principles with modern ICT tools
- Engages local communities in content creation and dissemination
- Provides scalable insights for development communication in tribal India
- **Results and Discussion**

The community-based radio communication initiative aimed to enhance agricultural knowledge dissemination and youth capacity-building among tribal populations. The intervention's outcomes over a six-month period reveal promising trends across participation, engagement, adoption, and feedback mechanisms.

- **1. Participation**

A total of 42 tribal youth were trained in content development, broadcasting, and rural communication. The program demonstrated a 75% retention rate over six months, indicating sustained interest and commitment among the participants. The retention can be attributed to the culturally relevant training modules, peer-led support systems, and integration of local knowledge systems into the broadcasting curriculum. High retention also suggests that such participatory communication efforts can be effectively scaled in similar rural and tribal contexts, offering long-term sustainability when locally owned.

Supporting Insight: According to UNESCO (2015), community media initiatives are more effective when community members themselves are engaged as content creators, leading to higher ownership and sustainability UNESCO, 2015 – Community Media Sustainability.

2. Engagement

•There was a 30% increase in farmer interaction with the radio content, measured through call-ins, SMS feedback, and participation in village listening groups. This surge reflects the growing relevance of the program's content, particularly in addressing real-time agricultural challenges such as pest outbreaks and climate variability. Additionally, 57% of listeners reported implementing at least one advisory received via the radio, highlighting the program's practical impact.

This shift aligns with the Uses and Gratification Theory, where audiences seek out media that meets their informational and practical needs (Blumler & Katz, 1974). The trust cultivated through localized voices and dialects, combined with actionable content, likely contributed to this increased interaction.

- **3. Adoption of Sustainable Practices**

The data indicates a 22% improvement in the use of organic pest control methods and the adoption of drought-resilient seed varieties among the target farming communities. These figures suggest a positive behavioural shift towards sustainable agricultural practices, a critical need in drought-prone and ecologically fragile regions. Adoption was particularly strong in areas where radio content was supplemented with community demonstrations and follow-up by local agri-volunteers.

Case Comparison: Similar outcomes were observed in the "Radio Farm School" model implemented in Maharashtra, where sustained radio programming led to increased uptake of sustainable farming practices (Mittal & Mehar, 2016 – IFPRI Discussion Paper 01533 Link).

4. Feedback Loop and Iterative Improvements

The implementation of monthly review sessions—involving tribal youth broadcasters, agricultural experts, and listener groups—proved essential in maintaining relevance and responsiveness. These sessions allowed for the continuous refinement of content based on community needs, seasonal concerns, and listener feedback. This participatory approach reflects the principles of Development Support Communication (DSC), where two-way communication channels enhance the effectiveness and credibility of media interventions

Theoretical Relevance: This strategy resonates with the Westley and MacLean's model of communication, which emphasizes feedback and multiple points of interaction to improve communication effectiveness.

Conclusion

The findings indicate that when tribal youth are empowered as communicators, and content is both participatory and context-sensitive, community radio becomes a transformative tool for knowledge dissemination and behavioural change. The combination of increased engagement, measurable adoption of sustainable practices, and effective feedback loops illustrates the potential of community radio as a scalable, low-cost model for rural development communication.

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ENTOMOPATHOGENIC NEMATODES AS A BIO-WEAPON FOR MANAGEMENT OF WHITE GRUBS

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Introduction

White grub is the one of the important pests of many crops which is known as May-June beetles or Chafer beetles or Leaf chafer. White grub, *Holotrichia consanguinea* (Blanchard) is considered as key soil dwelling insect which belong to family Melolonthidae and order Coleoptera. It mostly feeds on the roots of the crops. Nearly, 300 species of white grub reported from the India till now. Due to its wide host range and damage, it also identified as National pest. In India, this pest is distributed in Karnataka, Punjab, Assam, Jammu and Kashmir, Himachal Pradesh, Gujrat, Haryana, Uttar Pradesh, Tamil Nadu, Bihar, Rajasthan and Maharashtra. The presence of one grub/m^2 may cause 80-100 per cent plant mortality. Yield reduction occurs because larvae kill plants in the seedling stage and impair pod production by weakening the plants. White grubs also damage pods causing direct yield losses. Maximum damage occurs when the grubs are in 3rd instar. This pest showed certain levels of behavioural resistance to different class of insecticides, hence successful control of this pest is some extent difficult. Entomopathogenic nematodes (EPNs) are the nematodes which has ability to kill and parasitize the insect pest that's why they can be used as the successful bio-control agent against insect-pests management. Globally, 17 species of genus *Heterorhabditis* and 100 species of genus *Steinernema* have been reported that are found to be lethal for insect pests. In India, EPNs specially belongs to members of genus Steinernema (27 species) and *Heterorhabditis* (8 species) are the effective bioagents for the pest management.

Mode of action of EPNs: Species that use the ambush strategy include *Steinernema carpocapsae* and *S. scapterisci*, which wait for the victim with an upright body and reach it with a jump up to 5 mm long; their action is mainly directed against arthropods that are present and active on the soil surface. *Heterorhabditis* spp., *Steinernema glaseri*, and *S. apuliae* are more mobile and actively search for prey in the soil (the cruiser strategy). Upon entry through natural body openings (mouth, spiracles, anus) or directly through the cuticle (*Heterorhabditis* spp.), the IJs release their bacterial symbionts (genus, *Steinernema-Xenorhabdus* spp. and genus *Heterorhabditis- Photorhabdus* spp.). The bacteria (gram-negative and facultative belongs to enterobacteriaceae family) proliferate inside the host, producing *exo*- and *endo*-toxins that kill the grub and prevent secondary infections. Symbiont also produces antifungal and antibacterial metabolites like Xenorhabdin, Xenocoumacins, Xenoxodus, Nematophines (3' indol ethyl 3' methyl-2' oxo) and soluble proteineous compounds which make EPN a broad spectrum bioagents for biological suppression of agricultural pests. Nematodes feed on the bacteria and decomposed host tissues, develop into adults, reproduce and release new infective juveniles into the soil. EPNs are found in soil and are mostly lethal to wide host range of insect pests.

Safety concern of EPNs: Due to this high degree of safety compared to chemicals, application of EPNs does not require special safety equipment's and reduces time. Also, they have no residues, avoid ground water contamination, general environmental pollution and are safe to pollinators and arthropod parasites.

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Adaptability to climate: Generally, most of the bioagents takes days to weeks to kill the certain level of the insect population. But IJs of EPNs takes 2-3 days to kill specific amount of insect population. Extreme hot and extreme cold conditions will affect moderately to the immature stage of EPN species and strains are better adopted to wide range of environment conditions with long persistence in soil. As we see to the different species of the EPNs in India, *Steinernema riobrave* was first time reported from Gujarat state. Besides these few more species were discovered during last decade in India and many scientists have taken keen interest in entomopathogenic nematodes as an arsenal for soil insect pests in the country.

Efficacy against white grubs: Several studies have shown the effectiveness of EPNs against white grubs in laboratory as well under field conditions:

EPN species	Target insect-pest	Lab/ Crop	Efficacy (%)	Reference
Steinernema longicaudum X-7 and *Heterorhabditis bacteriophora H06*	*Holotrichia parallela*	Peanut	70 %	Guo *et al.*, 2013
S. abbasi	*L. lepidophora* 2nd instar	Laboratory	22.5 – 75.0 %	Patil *et al.*, 2017
H. indica	*Leucopholis lepidophora* 2nd instar	Laboratory	37.5 – 93.8 %	
Heterorhabditis indica	*Holotrichia serrata* and other species of white grub	Groundnut	73.34 %	Kamaliya *et al.*, 2019
Heterorhabditis indica	*Holotrichia serrata*	Onion	95.28 %	Divya *et al.*, 2019
Heterorhabditis beicherriana NCWZ1, *H. bacteriophora* HQ4 and *H. beicherriana* LJ24	*Holotrichia parallela, Anomala corpulenta* and *Holotrichia oblita*	Sweet potato	>70 %	Juan *et al.*, 2024

Factors affecting efficacy:

1. **Soil Moisture and Texture**: EPNs require moist conditions for mobility. Sandy loam soils facilitate better movement than heavy clays.
2. **Temperature**: Optimal temperatures range between 20–30°C for most EPN species.
3. **Host Stage**: Younger instars of white grubs are more susceptible than mature larvae.
4. **Application Method**: Uniform soil drenching or irrigation after nematode application enhances establishment and infection

Mass production of EPNs:

In-vivo* and *in-vitro

EPNs can be easily multiplied on the *Galleria mellonella* larvae due to its susceptibility to EPN and ease in rearing under laboratory conditions. Around 250-300 IJs of EPN is inoculated on fully grown larvae in each Petri plate. After 24-48 hrs discoloured larvae are collected, rinsed in water, incubated for three days and placed on white trap for emergence. Nematodes harvested from white traps are cleaned and packed polypropylene covers. The cleanly nematodes are ready for field application.

Formulations of EPNs: There are various formulations available in market but aqueous suspension is the one of the effective methods for application.

- **Aqueous Suspension**: IJs are mixed in water and applied using sprayers or irrigation systems.
- **Soil Drenching**: Direct application near the root zone of the crop.
- **Combination with Organic Amendments**: Use of neem cake or compost increases the persistence of EPNs in soil.
- **The sponge-based**: formulations are generally prepared by applying an aqueous nematode suspension at the rate of 500-1000 IJs per cm^2 surface area resulting a quantity of 5-25 million IJs per sponge placed in a plastic bag for storage for a period of 1-3 months at 5-10^0C.
- **Gel**: Formulations made by using activated carbon powder, polyacrylamide, hydrogenated vegetable oil paste containing mono and diglycerides. However, these formulations were unsuccessful due to low stability, less survival time, desiccation tolerance and viability of IJs.

Storage and transportation: The most common EPN formulation is an aqueous suspension. These nematodes are subjected to storage for later use and transportation for wide applications either in bulk or formulations. Infective juveniles can be stored in an aqueous suspension at 4-15 °C (depending on nematode species) without much loss of activity for 6-12 months for *Steinernema* species and 3-6 months for *Heterorhabditis* species.

Advantages over chemical control

- Target-specific action with minimal risk to non-target organisms.
- No chemical residue or environmental contamination.
- Potential for integration into Integrated Pest Management (IPM) programs.

Limitations and Challenges

- Sensitivity to UV light, desiccation, and extreme temperatures.
- Short shelf-life and need for refrigerated storage.
- High cost of commercial formulations compared to chemicals

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Revolutionising Indian Agriculture with Artificial Intelligence: A New Era of Farming

Chandrika Nigam

Introduction

Indian agriculture is at a turning point because it is now embracing Artificial Intelligence (AI) to boost productivity, sustainability, and farmers income! AI refers to the ability of a computer or machine to do tasks that usually require human intelligence thus making life easier. And as India strides toward the Digital India mission, the integration of AI in agriculture ensures security, economic growth, and environmental stability.

Key AI Advancements in Indian agriculture:

1.Smart Crop Monitoring

AI-powered drones and sensors detect crop health issues early, helping farmers act before damage spreads.

2. Climate-Adaptive Farming

AI tools provide localised weather forecasts and sowing advice, helping farmers adapt to unpredictable monsoons and droughts.

3. Soil and Resource Optimisation

AI analyses soil data to recommend ideal crops, fertilisers, and irrigation, reducing input costs and improving yields.

4. Market Intelligence

AI predicts crop prices and market trends, allowing farmers to sell smart and reduce dependency on middlemen.

5. Automated Machinery

AI-driven tractors and irrigation systems are boosting efficiency.

Indian Agri-Tech advice:

Startups like CropIn, Fasal, and Intello Labs are using AI to provide real-time farm analytics, quality assessment, and decision-making tools reaching thousands of farmers across India.

For seeking benefits we must consult Government officials and get their support plus the subsidies as well as know about localised affordable tech solutions. Attending latest farmer training programs is a sure-shot way to learn more about AI.

Conclusion

AI is already shaping the Indian agriculture with smart planning, innovation, and support thereby empowering farmers, enhancing food security, and leading India into an intelligent farming era. What are you waiting for?

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Precision Farming: Tools and Techniques

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Precision farming is a new agricultural method that utilizes technologies to maximize input use efficiency, increase the productivity of crops, and ensure sustainability. Through the use of technologies like GPS, GIS, remote sensing, aerial vehicles, soil sensors, and data analysis, farmers are able to track field variability and make well-informed, site-specific management decisions. These methods allow for effective management of resources, lower costs of production, and reduced environmental effects. With agriculture under growing pressure from climate change and scarcity of resources, precision farming presents a smart, data-based solution to guarantee food security and economic sustainability. This abstract brings to the fore the key tools and methods that define the future of sustainable agriculture.

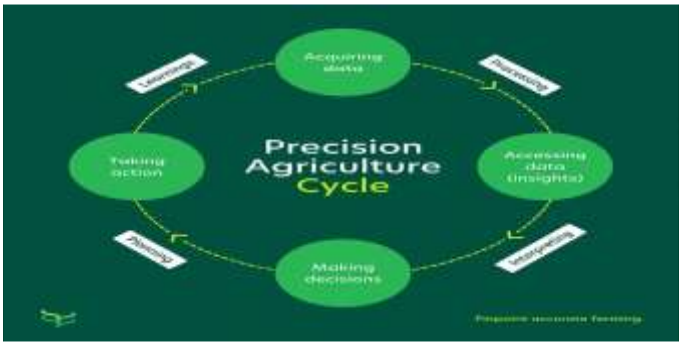
Introduction

Precision farming, or precision agriculture, refers to a revolutionary way of managing farms using sophisticated technologies to monitor, quantify, and react to variability of crops, soils, and environmental factors. The objective is to maximize agricultural inputs—water, fertilizers, and pesticides—while maximizing productivity, sustainability, and profitability. With the increasing necessity of feeding a growing population amidst the impacts of climate change and resource constraints, precision farming is an evidence-based solution. Precision farming combines advanced tools such as GPS, Geographic Information Systems (GIS), drones, remote sensing, soil sensors, and IoT-based sensors in order to provide better decision support on the farm. These technologies allow site-specific management of crops, enabling farmers to adapt their practices according to real-time field conditions.This section discusses the most important tools and methods that comprise the foundation of precision agriculture, explaining their functions in enhancing efficiency, lowering input costs, and encouraging environmentally sustainable agricultural practices

What is Precision Farming?

Precision farming, or precision agriculture (PA), is a sophisticated method of farm management that makes use of innovative technologies to boost the effectiveness, productivity, and sustainability of agricultural operations. In contrast with traditional farming practices, which indiscriminately apply uniform treatments to whole fields, precision farming acknowledges that no two areas of a field are identical. With real-time data gathering and sophisticated analytical programs, farmers are able to make decision-making that is focused on specific regions of a field.

This method utilizes different digital technologies like Global Positioning System (GPS), Geographic Information Systems (GIS), remote sensing, Internet of Things (IoT) sensors, drones, automation, and machine learning algorithms. These technologies together aid in observing soil health, crop status, weather fluctuation, and input needs, enabling accurate application of water, fertilizers, and pesticides.



Source: https://www.farm21.com/understanding-precision-farming

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Objectives of Precision Farming:

- Increase input use efficiency (fertilizers, pesticides, water).
- Increase crop productivity and profitability.
- Minimize environmental effects.
- Facilitate real-time decision-making.
- Optimize labor and resource allocation.

Requirement of Precision Agriculture in India:

- Fragmented farm holdings.
- Rising input costs.
- Vanishing natural resources.
- Climate variability.
- Growing food demand.

2. Essential Elements of Precision Farming

Precision farming is based on an ensemble of integrated technologies that function in concert to deliver accurate, site-specific information and management in farm operations. The following are the essential elements that contribute to precision agriculture being effective and efficient:

1. GPS and GNSS Technology

The Global Positioning System (GPS) and Global Navigation Satellite Systems (GNSS) are basic tools in precision farming. They make it possible for farmers to accurately define and monitor machinery and field zone locations. Applied in mapping farm boundaries, autonomous guidance of tractors, sampling of soils, and monitoring of yields. Makes farm operations such as seeding, spraying, and harvesting high-precision by eliminating overlaps and saving on inputs.

2. Remote Sensing

Remote sensing is the process of capturing data with satellites or drones that have cameras and sensors. Assists in determining crop health, disease or pest outbreak, water stress, and nutrient deficiencies. Aids in the computation of vegetation indices like NDVI (Normalized Difference Vegetation Index), assisting in the monitoring of crop vigor and yield prediction.

3. Geographic Information System (GIS)

GIS is a system for capturing, storing, analyzing, and displaying geographic or spatial data.

- Combines data such as soil type, elevation, and crop yield to develop exact farm maps.
- Enables site-specific management, soil fertility analysis, and variable rate input application.

4. Variable Rate Technology (VRT)

VRT enables accurate application of seeds, fertilizers, and chemicals in different quantities over different sections of the field.

- Improves input efficiency by applying resources where they are most required.
- Aids in minimizing input cost with enhanced crop response and yield.

5. Yield Monitoring and Mapping

Yield monitors mounted on harvesters record grain flow, moisture, and harvested area.

- Produces yield maps that uncover productivity differences across a field.
- Helps farmers make informed planning decisions for subsequent crop cycles with the aid of spatial yield information.

3. Advanced Tools Used in Precision Farming

Tool	Description	Function
Drones	Unmanned aerial vehicles	Crop scouting, NDVI imaging,

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(UAVs)	equipped with cameras and sensors	pesticide spraying
Soil Sensors	Devices embedded in the soil	Measure pH, temperature, EC, and moisture
Climate Stations	On-field weather monitoring systems	Collect temperature, humidity, rainfall, and wind data
IoT Devices	Internet-enabled sensors and machines	Real-time monitoring and automated decision-making
Mobile Apps	Digital advisory tools for farmers	Weather forecast, input schedule, pest alerts
AI and ML Platforms	Data analysis systems	Predict yields, recommend inputs, detect diseases

4. Techniques in Precision Farming

Precision agriculture utilizes a broad range of advanced methods that enable the management of spatial and temporal heterogeneity in agricultural fields. These methods enable optimum allocation of resources, enhanced productivity, and sustainable agriculture. Some of the major methods utilized are discussed below:

1. Site-Specific Crop Management (SSCM)

Site-Specific Crop Management is the practice of adapting agricultural operations based on the conditions of individual zones of a field instead of treating the whole field as one homogenous unit.

- It comprises soil analysis, crop scouting, remote sensing, and yield mapping.
- Through the use of exact doses of inputs such as seeds, fertilizers, and pesticides only where they are required, SSCM enhances input efficiency, minimizes wastage, and maximizes yield.

2. Grid Soil Sampling

This method entails soil sampling in a grid pattern, generally every 0.5 to 1 hectare.

- The samples so obtained are analyzed for nutrient status, pH, organic matter, and salinity.
- The findings are employed to generate soil fertility maps, which aid in the planning of site-specific nutrient management (SSNM) and liming or gypsum application for areas where it is necessary.

3. Precision Irrigation

Water is a valuable input in agriculture, and its usage efficiency is essential. Precision irrigation employs drip or sprinkler systems supported by soil moisture sensors and weather information. Provides water at the appropriate time and location, minimizing evaporation losses and waterlogging. Dramatically enhances crop water-use efficiency and facilitates sustainable groundwater management.

4. Automated Machinery

Precision farming utilizes autonomous tractors, GPS-guided seeders, robotic harvesters, and planters with artificial intelligence. These machines carry out activities such as sowing, spraying, and harvesting with great precision and minimize labor requirements while enhancing productivity.

5. Crop Health Monitoring with AI

Through computer vision, machine learning algorithms, and high-resolution images (obtained from drones or smartphones), farmers can identify: Detects diseases, nutrient deficiencies, and weed

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infestations early. This allows for timely interventions and minimizes pesticide use, safeguarding the crop as well as the environment.

5. Precision Farming Applications and Benefits

Precision farming delivers site-specific solutions for contemporary agricultural issues through the facilitation of site-specific interventions. Through the deployment of digital tools and data analysis, precision farming maximizes input use and enhances crop performance. The following are the major areas where precision farming is extensively utilized:

Key Applications

1. Nutrient Management

Precision farming enables site-specific nutrient application, particularly nitrogen (N), phosphorus (P), and potassium (K). Based on soil test results and crop demand, variable-rate technology (VRT) applies the right nutrient dose in the right place, improving nutrient use efficiency and reducing leaching losses.

2. Pest and Disease Management

With remote sensing, image analysis using AI, and sensor networks, farmers are able to detect infestations of pests or outbreaks of diseases in areas of the field. This allows for targeted application of pesticides, reducing chemicals and production expenses while enhancing crop wellness.

3. Weed Control

Spot spraying methods utilize drone or camera-based systems to detect and apply herbicides to only weed-infested patches. This method reduces herbicide expenses and minimizes the environmental impact of bulk chemical spraying.

4. Water Management

Water availability is a severe limitation in arid and semi-arid areas. Precision irrigation based on moisture sensors, weather prediction, and automation enables efficient application of water via drip or sprinkler systems. This increases the efficiency of water use and minimizes wastage.

Key Benefits

- Lower Input Costs: Optimum utilization of fertilizers, pesticides, water, and energy can lower input costs by 15–30%.
- Increased Yields: Real-time monitoring and optimized input management result in yield gains of 10–25%.
- Environmental Conservation: Lower runoff, emissions, and chemical residues support soil and ecosystem health.
- Timely Decision-Making: Farmers receive timely and accurate information through real-time data and alerts.
- Improved Record-Keeping: Online platforms assist in accurate field history, input records, and yield tracking.
- Climate Resilience: Climate variability adaptation through smart irrigation and stress monitoring improves sustainability.

Case Study: Indian Scenario

Under Punjab Agricultural University (PAU) and ICAR-supported trials, usage of GPS-guided sowing in combination with variable-rate nitrogen application in wheat and paddy showed:

- Yield increments of 15–20%.
- Cost reductions by up to 25% on fertilizers.
- Enhanced nitrogen use efficiency along with lower environmental footprint.

6. Challenges in Adoption and Government Support

Even though digital agriculture has that much potential for change, there are a few major challenges that prevent its acceptance by small and marginal farmers in India.

1. High Initial Investment

Purchasing digital equipment like sensors, drones, and precision farming software is still far too

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expensive. Smallholder farmers comprise the bulk of India's agricultural community but usually don't have the capital or access to credit necessary for these types of investments.

2. Lack of Awareness and Training

Most farmers lack exposure to digital technologies and need to be trained on how to use devices, read data, and make educated decisions. The lack of systematic capacity-building programs at the local level also contributes to stifling adoption.

3.Connectivity Challenges

Internet connectivity and power supply remain unreliable in most rural regions. This restricts the utilization of cloud-based solutions, real-time monitoring systems, and mobile-based advisory services that serve as the core of digital agriculture.

4. Data Privacy and Ownership

Data privacy has been a growing concern, particularly when data harvested from farms is exchanged with private agritech firms. Farmers do not know what happens to their data, nor do they know who actually owns it, which creates suspicion in digital platforms.

5. Fragmented Landholdings

The fragmentation of small land holdings presents the greatest challenge to adopting precision agriculture technologies, which tend to work better on large, consolidated farms. In the absence of cooperative farming or communal services, technology adoption is limited.

Government Support & Schemes

The Government of India has launched a number of initiatives to encourage digital agriculture and address the above challenges:

- Digital Agriculture Mission (2021–2025): Seeks to adopt digital technologies in agriculture through public-private partnerships and innovation.
- National e-Governance Plan in Agriculture (NeGPA): Aims at the dissemination of information and services electronically to farmers.
- Sub-Mission on Agricultural Mechanization (SMAM): Facilitates the supply and availability of farm machinery.
- Startup Agri-Tech Incentives: Provides incentives with funding, incubation, and access to markets for agri-startups for encouraging innovation in digital farming.

Future Prospects

The prospects for digital agriculture in India are promising, fueled by accelerated technology developments and growing awareness. Prominent evolving trends are creating a more efficient, sustainable, and data-based agricultural future.

- Robotics and Automation are transforming farm operations by minimizing manual intervention and enhancing precision in processes such as sowing, weeding, and harvesting.
- Big Data Analytics facilitates predictive modeling of weather patterns, outbreaks of pests, and forecasts of yield, enabling farmers to make better-informed decisions.
- Blockchain Technology provides greater transparency and traceability of the agricultural supply chain to ensure equitable pricing and avoid fraud.
- Smartphone-based Precision Tools are democratizing precision agriculture by offering instant information on the health of soils, the condition of crops, and irrigation using easy-to-use mobile applications.
- Sustainable Precision Farming (SPF) focuses on incorporating conservation agriculture practices, including reduced soil disturbance, crop rotation, and optimized input use, to

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increase productivity while preserving natural resources.

Conclusion:

Precision farming holds the key to sustainable, profitable, and climate-smart agriculture. Although initial adoption is a challenge, its long-term benefits in terms of yield, environmental health, and resource efficiency are significant. With the integration of AI, IoT, and big data, the next decade will see a massive transformation in Indian agriculture, making precision farming a standard rather than an exception.

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EMERGENCE OF NEW ECO-FRIENDLY TEXTILES: AN OVERVIEW

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Introduction

In the textile industry, sustainability is regarded as the most important feature of textile products. Current trends in textile fashion companies are to focus more on sustainable products, so that they can meet the environmental and social aspects and also support the economy of the company. Sustainable fibres offer solution for the textile industry facing concerns on environmental problems. Currently, these fibres are also favorable to satisfy the need and demands of quality products in the market.

Further in view of the limited natural resources such as resource intensive natural fibres (cotton fibres) and enviromnental impact of petroleum-based fibres (acrylic, polyester and nylon), the textile and apparel industry need to look for sustainable alternatives which does not pollute the environment. Things kept on changing with the time and textile researchers tried to seek out solution for the impacts of textile industry on the environment. Biodegradable fibres come from sustainable sources and are eco friendly in characteristics.

Generally natural fibers are mostly considered as more sustainable than synthetic fibers as consumption of resources is less in natural fibers production than synthetic fibers. However, cotton cultivation has high impacts on environment since large amounts of pesticides, fertilizers and water is needed for growing cotton. Currently, there is a major issue on the production of synthetic fibres mainly due to the social and ethical impacts through the emission of carbon thereby polluting the atmosphere. Thus, many eco-friendly and sustainable fabrics are developed from natural plant fibers and synthetic fibers made from natural resources in order to meet the required demands.

The new eco-friendly fabrics are mainly divided based on the sources of the fibres such as

1. Plant based fibres
2. Animal Based fibres
4. Recycled fibres

I. PLANT BASED FIBRES

These include those fibres which are obtained from plants that are grown in eco-friendly environmental conditions. Eg: Organic cotton, Hemp, Rami etc

A. Organic cotton: Organic cotton or low chemical cotton is a sustainable alternative of conventional cotton as it has social and environmental benefits, because organic cotton production is characterized with no use of synthetic pesticides, fertilizers or growth promoter or transgenic technology and less water consumption. Besides the environmental and agricultural benefits, organic cotton production is additionally an honest tool for social change because it includes ethical principles in its production system.

***Advantages*:** Reducing fertilizer and pesticide use, using water more efficiently and moving towards the use of locally available inputs such as green and animal manure are enabling conventional cotton farmers to enhance their impact on the environment and farming communities

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Disadvantages: Though organic cotton production is much valuable but it is very demanding, it needs lot of devotion, commitment and experience.

Uses: It is used to make from normal shirt to that of jackets and also a good fabric for the household materials.

B. Hemp: Hemp fabric comes from the stems of the *Cannabis sativa* plant. It is one of the fastest growing plants and required less water, energy, pesticide or fertilizers. Hemp is considered to be eco-friendly since this plant can be grown for many years in the same place without exhausting the soil.

Advantages: It has a similar texture to cotton and is not susceptible to shrinkage and also highly resistant to pilling. Since fibers from this plant are long and durable, hemp fabric is extremely soft but highly durable. Further, Hemp has very similar properties to linen.

Disadvantages: Though this hemp is recognized as a source of high tensile durable textile fibres, considering the psychoactive effect of *Cannabis sativa*, various rules and regulations in many countries has made difficult for the farmers to grow and produced this crop.

Uses: The primary use of hemp fabric is apparel (garments especially T-shirt), towel and table clothes.

C. Ramie: Ramie fibres are obtained from the bast of the plant (*Boehmeria nivea* L.). These fibres are silky, lustrous, unparallel strength, sturdy and easily blend with all other natural and manmade fibres. It is stronger than cotton, flax and lustre like the silk. It is resistant to micro-organism (bacteria) and infections.

Advantages: Ramie is frequently used in place of cotton. Ramie blended with several fibres, such as cotton, rayon, etc. increases the color, strength and luster. The ramie fibre has strong adsorption capacity and can prevent skin allergies and itching.

Disadvantages: Ramie is a labour intensive and input intensive crop in terms of planting material, plant nutrients and machines.

Uses: Ramie fabric is used for manufacturing shirting and suiting materials, bed sheets, curtains, etc.

D. Linen: Linen is a sustainable fabric made from flax fibers. It is one of the most biodegradable and stylish fabrics in fashion history. Natural colours of linen are ecru, grey, ivory, and tan.

Advantages: Linen are highly durable and can resist high temperatures thereby making the fabric generally perfect for rough uses such as exploring the forest. It can also absorb moisture without holding bacteria. Linen when wet is stronger than dry and the more it is washed, the more the fabric become softer and pliable.

Disadvantages: The laborious time it takes to produce linen yarn, and the manual processes that have to be undertaken.

Uses: It is used to make clothes to wear, table and kitchen clothes, towel, bedroom linens etc. Some painter uses its sheets for canvas painting.

E. Bamboo fibre: Bamboo fibre is regenerated cellulosic fibre made from the pulp of 3-4 years old bamboo plant. It is an outstanding biodegradable fabric material with strength similar to usual glass fibres. Furthermore, these fibres are highly durable with significant tensile strength.

Advantages: Bamboo fibres are eco-friendly and biodegradable. Besides anti-microbial properties, these fibres are hypoallergenic, hydroscopic and resistant to ultraviolet light.

Disadvantages: Vulnerable to moist and pest.

Uses: Bamboo fibres are used mainly in textile industry for making attires, towels, and bathrobes. Due to its antibacterial nature, it is used for making bandages, masks and sanitary napkins.

F. Pineapple fibre: Pineapple fibres are obtained as leaf fibres from pineapple leaves and are known as Pineapple Leaf Fibre (PALF) or "Pina" fibre. It is commonly blended with cotton, silk and polyester for making fabric. The PALF is softer and has high luster and is usually white or ivory in colour. PALF Fabrics are soft, durable and resistant to moisture.

Advantages: Pineapple fibres are biodegradable and required zero waste management. These fibres are light weighted and can be blended easily with other fibres. The absorption tendency of PALP is comparable to cotton.

Disadvantages: Undergo quick biodegradation. Cost of production is expensive since it is tedious, time consuming and labour intensive.

Uses: it is suitable for making clothing, accessories and home textile.

G. Orange fibre: Orange fibre is made by extracting the cellulose from the by-product of citrus "pastazzo" disposed from the industrial processing of the oranges. This was first developed and patented by two Italian Scientists Enrica Arena and Andriana Santanocito jointly with the University Politecnico di Milano in 2013. Orange fibre can be used to make good quality and sustainable fabrics and further made contribution in reducing the cost and the ecological impact of citrus pulp disposal. Further, an innovative vitaminic textile can also be produced by enriching the orange fibre with citrus fruit essential oil through nanotechnology.

Advantages: The fabrics made from orange fibres are soft, silky and lightweight. They easily can be blended with other materials. It adopts recycled and sustainable raw materials. The fabric made from orange fibres is eco-friendly and also good for the health since the vitamins A, C and E are present in the natural oils within the fabric.

Disadvantages: They have lower strength and need to be blended with other fibres for making fabrics.

Uses: they are used for garments, accessories and home textile.

2. ANIMAL BASED FIBRES

Animal based fibers are the second most widely used natural fibers after plant fibers. Examples of this fibre include wool fibre, silk, hair and feathers obtained from various animal sources.

A. Alpaca: This is the fibre obtained from the wool of camel "Alpaca" (Huacaya alpaca and the Suri alpaca) native to South America (Peru). Huacaya alpaca fibres are denser, softer and crimpy than that the Suri alpaca which is silkier without matted fibres. This fibre when blended with wool and silk are valued for its softness and warmth. Alpaca farming has practically low ecological impact as chemicals are not allowed on the animals or the land. Further, since the animals are raised freely on pastures (organic methods), there is no need for anti-parasitic drugs dip.

Advantages: Organic alpaca breeders don't harm the animals since shearing is done carefully annually corresponding to their natural shedding cycle. Due to its striking natural colouring of the alpaca, dyeing of the fibre is not required. The natural fleece colors which vary widely from whitest white to blackest black. Moreover, as compared to sheep wool, the alpaca wool is durable, soft and silky. Alpaca fibres are hypoallergic due to absence of lanolin (wool wax/grease) in this fibre. It is naturally water-repellent and difficult to ignite.

Disadvantages: The initial cost of production is expensive.

Uses: It is used to make winter wears such as sweaters, fleece jackets, suits, socks, gloves and hats.

B. Silk: Silk is the strongest natural animal fibre obtained from the secretion of silkworms. Different varieties of silkworms produce different quality of silk fibres. Soft silk fibres are obtained from the mulberry leaf eating silk worms while rough fibre from wild silk worms fed with other leaves like oak tree leaves.

Advantages: Besides being strongest natural fibres. Silk is hypoallergenic and a natural repellant of dust mites and fungus.

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Disadvantages**:** Expensive, delicate and prone to wrinkling.

Uses**:** Used in garment such saree, dupatta, shirt, etc

C. Sustainable leather: Leather can be considered as sustainable if the leather is a by-product of local farming and agriculture industries. That means the animals are primarily farm animals raised for meat purpose and not for the leather purpose.

Advantages**:** Leather is bio-degradable and eco-friendly made without using chemicals.

Disadvantages**:** During the process of tanning for production of leather, chrome is used and this led to the release of a considerable amount of toxic waste into waterways and also caused serious harm to industrial tannery workers.

Uses**:** It is used to make bags, jackets, belts, etc.

3. SEMI-SYNTHETIC FIBRES

Recently there is a shift from oil-based non-biodegradable synthetic fibers like polyester and nylon towards renewable and biodegradable synthetic fibers produced from natural resources.Thus, these are naturally eco-friendly, less resource consuming, recyclable and sustainable.

A. Lyocell: Lyocell fiber has emerged as an important class of regenerated cellulose. Its production is based on the N-methyl morpholine-N-oxide dissolution method which are simple, resource-conserving, and environmentally friendly method. Lyocell fibers are soft, silky, lustrous and bulky. Lyocell is 50% more absorbent than cotton.

Advantages**:** Apart from the environmental benefit, the lyocell fibers are also of high quality such as high strength and excellent tenacity in the wet state, excellent compliance with other fibers and excellent draping quality. Lyocell fibres are better than viscose fibres.

Disadvantages**:** The lyocell process is still in its early stage of commercial development in comparison with the well-established viscose process. Higher cost of production required.

Uses**:** It is used in production of mattresses, bed covers, conveyor belts, medical dressings etc.

B. **PLA (Polylactic Acid)** fibre is a biodegradable and bio-based synthetic fibre made from renewable resources like corn starch, sugarcane, or cassava. It is produced through the polymerization of lactic acid, which is derived via fermentation of plant sugars. PLA can be spun into fibres and woven or knitted into textiles, often referred to as PLA fabric.

Advantages: It is an eco-friendly alternative to conventional synthetic fibres. PLA fibre is biodegradable which help in reduction of environmental impact. PLA is also skin-friendly, lightweight, breathable, and resistant to UV rays, making it suitable for clothing and medical applications.

Disadvantages: It has low heat resistance and is less durable than conventional synthetic fibres like polyester or nylon. Additionally, PLA fabrics tend to be more expensive, require industrial composting to break down properly, and can be difficult to dye vibrantly.

Uses: PLA fabric is used for eco-friendly clothing, sportswear, underwear, medical and baby clothes.

4. RECYCLED FIBRES

Recycled fibres are term as fibres which are made with waste textiles materials through chemical or mechanical breakdown into fibres. Currently, in textile industry, recycling is needed not only due to the shortage raw materials but also to control or reduce pollution. The amount of energy, water and dye use is reduced from using a product that has already been processed. The advantages of recycled fibres are it reduces the cost of materials thereby increasing profitability. It reduces the environmental impacts through reduction of use of new raw materials. Recycling fabrics required less energy and lower the production cost.

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A. Recycled polyesters: Recycled polyester (rPET) is obtained by melting down existing plastic and re-spinning it into new polyester fiber. Recycled polyester provides a second life to a not biodegradable material that would have end up in landfill or the ocean.. In addition, recycled polyester contributes in reducing crude oil and natural gas extraction from the Earth to make more plastic.

***Advantages*:** Environmentally friendly by reducing the use of natural resources.

***Disadvantages*:** Some blended polyester can't be recycled. Recycled polyesters have lower quality compared to virgin polyester and may not be applicable for high quality textiles production.

***Uses*:** It is used to make footwear and sportswear.

B. Recycled cotton: Recycled cotton is obtained by converting waste cotton fabric into cotton fiber that can be reused in textile products. It is also commonly referred to as regenerated cotton, reclaimed cotton, or shoddy. Cotton can be recycled using old garments or textile leftovers. The quality of the recycled cotton is inferior to new cotton and usually generally blended with new cotton.

***Advantages*:** Recycled cotton is considered as a sustainable alternative since it prevents further textile waste and requires fewer resources than usual or organic cotton.

***Disadvantages*:** The quality of recycled fiber is inferior to virgin cotton. The fiber length and length uniformity are impacted limiting the end-use application. The production of recycled cotton is still very limited.

***Uses*:** Recycled cotton can be used as insulation, mop heads, rags and stuffing.

C. Recycled Nylon: Similar to recycled polyesters, recycled nylon also contributes to the reduction of uses of natural resources, energy and water than virgin. Waste materials from old fishing nets, nylon carpets, tights, etc are used for recycling.

***Advantages*:** Lower the resources utilization and environmental impact.

***Disadvantages*:** Quality of the recycled nylon are lower compared to virgin nylon.

Uses: Recycled nylon can be used to make bags and jackets.

CONCLUSIONS

Thus, in textile industry there is a need for a bio-based market which requires the switching of conventional natural raw materials such as petrochemical or mineral resources with eco-friendly and sustainable products from renewable resources with minimal environment impact. Sustainable fibres offer solution for the textile industry facing concerns on environmental problems. Biodegradable and sustainable fibres can overcome the impact of textile harmful chemicals as it has come from sustainable sources and are eco-friendly in characteristics.

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Microbial Secondary Metabolites– The Need for Sustainable Agrochemicals

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Introduction

Modern agriculture faces a paradox: while agrochemicals have significantly boosted productivity and protected crops from pests, weeds, and diseases, their overuse has led to environmental degradation, resistant pest species, loss of soil fertility, and negative effects on non-target organisms. According to *Priyanka et al. (2025)*, chemical pesticides and fertilizers, though effective, leave residues, contaminate water systems, and often affect beneficial microbes in the rhizosphere. Consequently, there is an urgent push to identify eco-friendly**,** biodegradable, and selective alternatives to conventional agrochemicals. One such promising avenue is the use of secondary metabolites from microbes. Unlike primary metabolites (involved in growth and reproduction), secondary metabolites are bioactive compounds not essential for microbial survival but critical for defense, signaling, and competition. These molecules can mimic or replace agrochemicals, offering antifungal, insecticidal, herbicidal, and growth-promoting effects (*Bhakat et al., 2025*).

Microorganisms such as *Streptomyces*, *Bacillus*, *Pseudomonas*, yeasts, and fungi produce diverse chemical scaffolds including alkaloids, phenazines, lipopeptides, siderophores, and polyketides, many of which show strong antimicrobial or plant growth-regulating activity. The specificity and environmental compatibility of these compounds make them ideal candidates for the next generation of agrochemical agents (*Henrie, 2024*). This review explores recent advances in the discovery, characterization, and agricultural application of microbial secondary metabolites as potential agrochemical substitutes, with a focus on their biopesticidal, biofertilizing, and biostimulant functions. It also examines challenges in commercialization and the future directions for integrating these bio-based solutions into sustainable agriculture frameworks.

Categories and Functions of Microbial Secondary Metabolites

Microbial secondary metabolites can be broadly categorized based on their bioactivity and structural class. Each category has unique agrochemical relevance:

1. Antimicrobials / Biopesticides

One of the earliest and most successful uses of microbial metabolites in agriculture has been in plant disease control. Compounds such as iturins, fengycins, and surfactins (produced by *Bacillus subtilis*) have strong antifungal properties and can suppress pathogens like *Fusarium*, *Rhizoctonia*, and *Sclerotinia*. Similarly, *Streptomyces* species produce streptomycin, actinomycin, and other polyketides that inhibit bacterial growth.Secondary metabolites are natural defense weapons of microbes that can inhibit phytopathogens with minimal toxicity to plants.(*Gupta et al., 2025*)

2. Plant Growth Promoters / Biostimulants

Some metabolites mimic or enhance plant hormones like auxins, gibberellins, or cytokinins, thereby stimulating root elongation, nutrient uptake, and shoot development. *Bacillus spp.* are known to

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release indole-3-acetic acid (IAA), while *Pseudomonas* produces siderophores that improve iron availability in the rhizosphere. Endophytic microbes promote plant health through secretion of growth-modulating metabolites. (*Bhakat et al., 2025*)

3. Herbicidal and Insecticidal Activities

Certain metabolites function as natural herbicides. These include phytotoxins that interfere with photosynthesis or root growth in weeds. For example, *Erwinia herbicola* produces herbicidal agents like rhizobitoxine. Similarly, insecticidal lipopeptides can disrupt insect gut membranes. Emerging evidence from marine microbes also shows production of unique metabolites with novel mechanisms of action, offering potential for managing herbicide-resistant weeds

Advantages, Challenges, and Commercialization Potential

Advantages Over Conventional Agrochemicals

- Eco-friendliness: Microbial metabolites are biodegradable and do not persist in soil or water bodies.
- Specificity: Unlike broad-spectrum pesticides, these metabolites often target specific pathogens or physiological processes.
- Resistance Management: Multiple modes of action help delay resistance buildup in pests.
- Soil Health: Promotes microbial biodiversity and supports sustainable soil ecosystems.

Challenges in Development and Use

- Yield Variability: Production of metabolites is sensitive to growth conditions and may vary across microbial strains.
- Stability: Many secondary metabolites are unstable under field conditions (UV, temperature, pH).
- Regulatory Barriers: Biopesticide registration can be complex due to lack of harmonized global frameworks.
- Cost: Initial R&D and formulation development may be costlier than conventional synthesis.

Future Research and Technological Approaches

The integration of genomics, proteomics, and metabolomics is enabling precise mapping of biosynthetic gene clusters involved in metabolite production. CRISPR-based genome editing is also being explored to upregulate specific biosynthetic pathways.Moreover, synthetic biology offers possibilities to transplant metabolite-producing genes into fast-growing microbial hosts for large-scale production. AI-powered compound screening is another frontier enabling identification of agriculturally relevant metabolites from databases.

Conclusion:

Microbial secondary metabolites represent a scientifically sound and environmentally friendly alternative to synthetic agrochemicals. Their potential spans pest and disease control, soil fertility enhancement, and plant stress resilience. However, realizing this potential at scale requires addressing challenges in formulation, regulation, and public awareness. In a time of climate change, declining soil health, and pesticide resistance, microbial metabolites may be the missing link in achieving truly sustainable agriculture.

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Drone and Remote Sensing Applications in Crop Monitoring

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Introduction

Modern advancements in agricultural technology have completely redefined the process of crop management by farmers and researchers, from the conventional method of manual observation to extremely effective data-based technologies. Of these technologies, drones and remote sensing are proving to be immensely strong real-time crop monitoring tools, which provide unprecedented precision and extent. Drones, with high-resolution cameras and sensors, can take sharp aerial images of fields, allowing early identification of infestations by pests, nutrient deficiencies, water stress, and other abnormalities. Remote sensing, based on both aerial platforms and satellites, offers timely multi-spectral and thermal information useful for precision agriculture decision-making. By combining these technologies, farmers can track the health of crops, make irrigation schedules more efficient, use fertilizers more efficiently, and minimize environmental degradation. These developments do not only enhance profitability and efficiency but also play a very important role in sustainable agriculture, providing food security for a large population of the world while preserving natural resources.

1. Crop Monitoring Role of Drones

Drone technology has become one of the most powerful innovations in contemporary agriculture, allowing farmers to receive exact, real-time data to improve crop management. They are versatile and can quickly scan vast areas, making them an integral part of precision farming systems.

Aerial Imaging

Aided by high-resolution RGB cameras, drones are able to take high-level detail aerial photographs that expose crop conditions from above. The images assist in detecting differences in plant growth, lodging detection, weed infestation spotting, and flood or storm damage assessment. Real-time data is captured, enabling farmers to make corrective measures immediately.

Precision Agriculture

High-tech drones are equipped with multispectral, hyperspectral, or thermal cameras that can recognize minute changes in plant health that are not observable with the naked eye. They can measure vegetation indices like NDVI (Normalized Difference Vegetation Index), which reflect plant health and chlorophyll content. This allows for early identification of crop stress due to pests, diseases, nutrient deficiencies, or drought preventing losses in yield.

Spraying and Seeding

The advanced agric drones have the ability to carry loads for precision pesticide and fertilizer spraying. In contrast with traditional approaches, drone spraying provides consistent coverage while minimizing wastage of chemicals, lessening environmental pollution, and sparing workers from exposure to toxic chemicals. Precision seeding is also supported in some drones, particularly in challenging environments or remote areas, enhancing efficiency and lowering labor expenses.

Mapping and Planning

By creating accurate 2D orthomosaic maps and 3D models of fields, drones enable farmers to better plan irrigation patterns, drainage systems, and planting designs. Such digital maps further aid in determining areas with waterlogging or erosion issues, thereby enhancing land-use efficiency. The data gathered from drone mapping may be integrated with

Geographic Information Systems (GIS) for long-term monitoring and strategic decision-making.

2. Applications of Remote Sensing

Remote sensing has transformed agricultural monitoring through the delivery of high-scale, repeatable, and accurate information on crops and the environment without direct contact in the field. With satellites, aerial platforms, and unmanned aerial systems (UAVs), remote sensing technologies obtain data in various wavelengths of light to produce useful information for farming.

Source, Wang et al., 2024

Figure-1 Use of remote sensing in Agriculture

Satellite Imagery

Satellite imagery with high resolution facilitates constant and extensive monitoring of agricultural territories, allowing one to monitor crop conditions across whole regions. The assessment of crop acreage, the early detection of disease epidemics, and the evaluation of the effects of weather phenomena become possible. Contemporary satellites like Sentinel-2, Landsat-8, and PlanetScope provide repeated observations over short time intervals, providing timely information for prompt interventions.

Vegetation Indices (NDVI, SAVI)

Indices of vegetation such as NDVI (Normalized Difference Vegetation Index) and SAVI (Soil Adjusted Vegetation Index) are quantified from satellite or aerial photos to evaluate plant health, biomass production, and leaf cover. NDVI compares near-infrared (vegetation highly reflects) versus red light (vegetation absorbs), reflecting plant health. SAVI, on the other hand, corrects for soil reflectance, thus applicable in sparse vegetative cover areas. The indices enable the detection of crop stress at an early stage before visual signs become evident.

Weather and Climate Monitoring

Remote sensing information is combined with meteorological data to observe climatic trends and forecast the onset of droughts, floods, frost, or heatwaves. With such warnings in advance, farmers are able to take precautionary steps such as altering planting dates, altering irrigation timing, or cultivating climate-tolerant crop types.

Soil and Moisture Analysis

Remote sensing equipment, such as microwave and thermal sensors, is able to detect soil moisture changes at the field and regional scales. This data is crucial in designing effective irrigation plans, avoiding water stress, and maximizing the utilization of water. Further, spectral analysis will indicate soil texture, organic matter levels, and salinity, aiding in improved soil management.

3. Advantages to Farmers

The use of drones and remote sensing in farming brings various benefits that have a direct positive impact on farmers' productivity, profitability, and sustainability.

Enhanced Decision-Making

Availability of precise, high-resolution, and timely information enables farmers to make sound decisions on planting, irrigation, fertilization, and pest management. Through observing crop conditions using aerial imagery and vegetation indices, farmers are able to pinpoint particular problem areas and react with precision instead of speculation.

Reduction in Input Costs

Targeted interventions like spot application of fertilizers, spot spraying of pests, and optimized irrigation reduce wastage of resources. This not only reduces seeds, water, and chemical costs but also reduces pollution of the environment and enhances input-use efficiency.

Early Detection of Problems

Drones and remote sensing can detect crop stress, pest infestations, and nutrient deficiencies early sometimes before any visible symptoms show. Early detection allows farmers to take corrective action, avoiding damages to yields and cutting down on the use of large quantities of chemical treatments.

Higher Yield and Quality

Accurate monitoring guarantees crops get the correct quantity of nutrients and water at the appropriate moment, resulting in healthier plants and better harvests. More effective crop management means higher production, improved produce quality, and better market value, ultimately enhancing farm income.

4. Challenges

Although drones and remote sensing bring important advantages to agriculture, their use is not without challenges. Various practical, financial, and technical constraints must be overcome for broader application, particularly in smallholder farming systems.

High Initial Investment

The expense of acquiring drones, high-resolution cameras, multispectral sensors, and related software can be very expensive for small and medium-scale farmers. While rental options and cooperative ownership schemes are on the rise, affordability is still a significant hindrance.

Need for Skilled Operators and Technical Knowledge

Special skills are needed to operate drones, take quality images, and analyze remote sensing data. Farmers can get training or have access to expert services to utilize these technologies fully. Without proper technical knowledge, the potential of these tools will remain untapped.

Data Processing and Interpretation

Raw data gathered by drones and satellites will have to be analyzed through sophisticated software and analytical tools to produce usable insights. This entails not only computational resources but also technical know-how that might be lacking in rural regions.

Weather Limitations

Drone operations rely on good weather. Wind, rain, fog, or heavy cloud cover can impede drone flights and diminish image quality, lessening data reliability during periods of poor weather.

5. Future Prospects

The future of crop monitoring is the seamless integration of drones, remote sensing, and data analytics. Artificial Intelligence (AI) and Machine Learning (ML) are likely to play a game-changing role by automating analysis of images, real-time detection of crop anomalies, and generating predictive models for yield forecasting and pest/disease outbreaks. Cloud platforms will enable farmers to receive processed information immediately on mobile phones, which will facilitate quick decision-making anywhere. Integration with the Internet of Things (IoT), like soil monitors, weather stations, and automated irrigation systems, will make a completely integrated "smart farm" system. These technologies will play a key role in sustainable and climate-resilient agriculture for the next few decades, ensuring food availability while minimizing the environment footprint.

Conclusion

Drone and remote sensing technologies have completely transformed crop monitoring by providing precise, efficient, and environmentally sustainable solutions for contemporary agriculture.

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By facilitating early detection of problems, maximizing resource utilization, and enhancing yield quality, these technologies allow farmers to shift towards precision and eco-friendly farm systems. Although limitations like cost, technical expertise, and weather conditions prevail, ongoing technological progress, government incentives, and capacity-building schemes are gradually bridging these impediments. With the mainstreaming of AI, ML, and IoT integration, these will not just make agriculture more productive but also make it more resilient against the threats of climate change.

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Post-Harvest Loss Assessment in Key Crops

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Post-harvest losses have considerable effects on the amount and quality of farm produce between harvest and consumption. Post-harvest losses take place at different stages of harvesting, drying, storage, and transportation. Farmers' revenue and food supply decrease through quantitative and qualitative losses. The causes, measurement, and managing of losses in major crops, government actions, and capacity building to promote food security and sustainable agriculture are emphasized in this bulletin.

1. Introduction

Post-harvest losses (PHLs) are a serious concern in world agriculture. They are the deterioration in quantity and quality of food products from harvest to consumption. In most developing nations, including India, 20–30% of the total agricultural produce is lost at the post-harvest stage because of improper handling, inadequate infrastructure, absence of awareness, and lack of storage and processing facilities. Reducing post-harvest losses is not only crucial to food security, but it also helps to enhance farmers' income and alleviate environmental pressures from surplus production. This bulletin provides a detailed analysis of post-harvest losses in major crops and the interventions to reduce them.

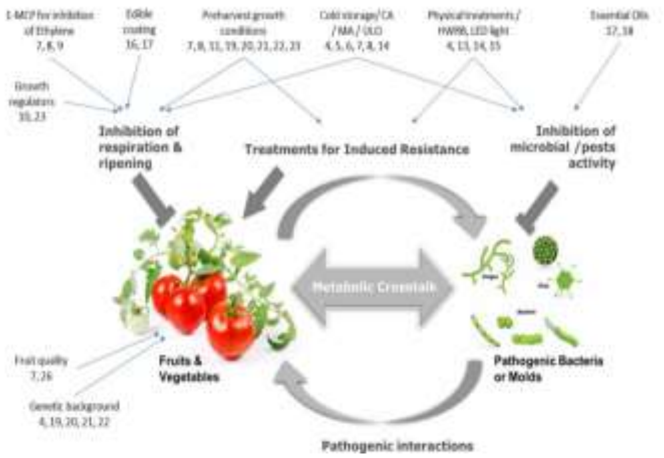
2. Definition of Post-Harvest Losses (PHLs)

Post-harvest losses are quantifiable reductions in the amount and quality of farm products during the different phases after harvesting, such as handling, storage, processing, packaging, transport, and marketing. Post-harvest losses have great implications on food security, farmers' revenues, and the efficient use of resources.

Quantitative losses are the actual loss of volume or weight of the produce. This can be a consequence of mechanical damage during threshing or harvesting, spillage while in transit, pest attack, or microbial rot while in store. Grains, for example, can be consumed by rodents or lost through poor packaging and handling.

Qualitative losses, however, imply the reduction of the nutritional, market, or consumer quality of the produce. These consist of the loss of taste, texture, appearance, color, or nutrient quality due to causes such as mold development, biochemical reaction, insect infestation, or exposure to inappropriate temperatures and humidity.

Collectively, these losses lower the marketability and utility of food crops and may account for as much as 30% of output in certain crops. Efficient post-harvest handling is critical to lower such losses and provide consumers with safe, healthy, and high-quality food while enhancing profitability for producers.



Source: https://www.mdpi.com

3. Phases of Post-Harvest Loss

Post-harvest losses are cumulative and take place at every step in the chain from farm to consumer. The major stages are:

1. Harvesting: Losses arise due to too early or too late harvesting, incorrect methods, or mechanical damage, resulting in shattering or bruising.

2. Threshing/Shelling: Ineffective processes can lead to grain breakage or loss while separating produce from plant material.

3.Drying: Insufficient drying results in excessive moisture content, promoting susceptibility to fungal invasion, spoilage, and insect infestation.

4.Cleaning and Grading: Inadequate grading lowers market value, while improper removal of contaminants jeopardizes food safety and quality.

5.Packaging: Poor packaging in improper or damaged containers results in spilling, contamination, and quality degradation.

6.Transportation: Crude handling, overloading, and poor road conditions result in physical damage and spoilage, particularly in perishables.

7.Storage: Insects, rodents, moisture, and microbial activity cause major losses in both quantity and quality.

8.Marketing and Processing: Delays, poor infrastructure, and inadequate processing techniques further degrade produce quality.

4. Causes of Post-Harvest Losses

Cause	Examples
Mechanical Damage	Bruising, cuts during harvesting, threshing
Biological	Pest infestation (insects, rodents), microbial spoilage
Chemical	Oxidation, discoloration, nutrient degradation
Environmental	Humidity, temperature fluctuations
Infrastructural	Poor roads, lack of cold chains, inadequate storage
Human Factors	Lack of skill, poor packaging, unscientific drying

5. Assessment of Post-Harvest Losses in Key Crops

Post-harvest losses are very variable across crop types because of variation in physical structure, perishability, storage needs, and handling. The following evaluation tabulates the estimated losses, principal causes, and feasible interventions for reducing post-harvest losses in broad crop groups.

A. Cereals

1. Rice (Oryza sativa)

- Total Losses: 8–12%
- Broad Causes: Shattering during harvest, incorrect threshing practices, excessive grain moisture at storage, and insect or rodent attack at storage.
- Assessment: Losses are greatest during threshing (about 3%) and storage (about 4%). Better harvesting timing and drying methods are crucial.

2. Wheat (Triticum aestivum)

- Total Losses: 6–10%
- Causes: Delayed harvesting, poor drying, and rodent infestation in unscientific godowns.
- Assessment: Efficient drying and application of aerated godowns can reduce these losses

B. Pulses

1. Chickpea (Cicer arietinum)

- Total Losses: 6–9%
- Causes: Insect infestation, particularly by Callosobruchus (bruchid beetles), and excess moisture during storage.

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- Assessment: Encouraging seed treatment and adoption of hermetic storage (e.g., metal bins or PICS bags) is advisable.

2. Pigeonpea (Cajanus cajan)

- Total Losses: 7–10%
- Causes: Shattering of pods at maturity and fungal infection during slow drying.
- Assessment: Adoption of mechanical threshers that minimize breakage and proper timing of drying can minimize losses.

C. Oilseeds

1. Mustard (Brassica juncea)

- Total Losses: 10–15%
- Causes: Shattering of mature pods, inadequate post-harvest handling, and poor packaging practices.
- Assessment: Early harvest and use of pod shatter-resistant varieties can minimize losses.

2. Groundnut (*Arachis hypogaea*)

- Total Losses: 12–18%
- Causes: Drying and storage mold growth, and aflatoxin contamination.
- Assessment: Dry in clean surfaces and post-harvest curing are essential practices.

D. Fruits and Vegetables

1. Tomato (*Solanum lycopersicum*)

- Total Losses: 25–30%
- Causes: Handling bruising, premature ripening in storage, and fungal rot.
- Assessment: Utilizing ventilated plastic crates and determining cold chains can minimize deterioration.

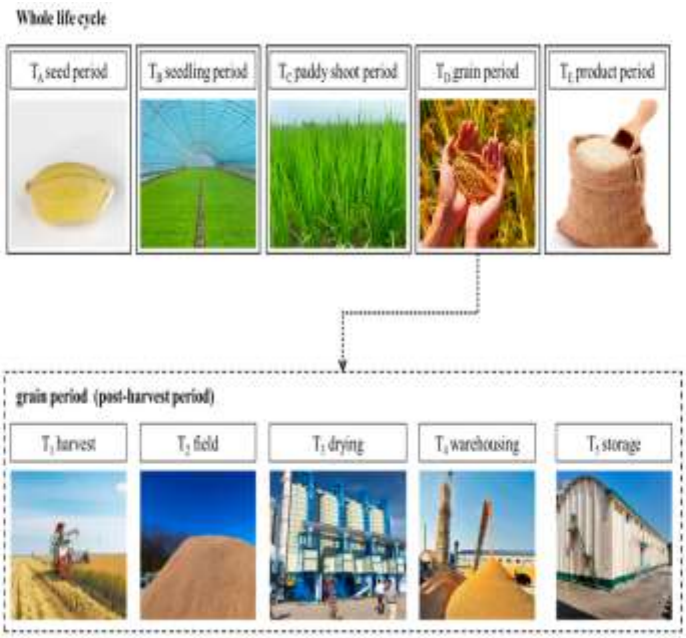
2. Mango (*Mangifera indica*)

- Total Losses: 30–35%
- Reasons: Sap burn, early ripening, mechanical injuries, and improper packing.
- Assessment: Pre-cooling, ripening chambers, and cushioning in packaging should be practiced.

E. Root and Tuber Crops

1. Potato (*Solanum tuberosum*)

- Total Losses: 10–20%
- Reasons: Sprouting, greening due to light, microbial rot, and bruising during handling.
- Assessment: Controlled storage at refrigeration and anti-sprouting treatment can greatly minimize post-harvest damage.



Source: https://www.mdpi.com

6. Methods of Loss Assessment

Post-harvest losses estimation is very important to prepare effective strategies to reduce them. Several scientific and participatory techniques are employed to estimate both quantitative and qualitative losses in various crops and at different stages of the post-harvest supply chain. The most important methods are described below:

A. Empirical Field Surveys

Empirical field surveys are among the most popular techniques to measure post-harvest losses under actual farm conditions. These include:

- Sampling of crops at various post-harvest stages such as harvesting, threshing, drying, storage, and transport.
- Comparison between planned yield (on the basis of pre-harvest estimates) and actual amount harvested or sold.
- Visual checks and weight measurement are done to arrive at physical loss, contamination, or quality losses.

B. Storage Experimentation

In this approach, crops are stored in a simulated environment under controlled conditions to monitor the nature and magnitude of losses over time. Researchers evaluate:

- Infestation by pests and rodents
- Bacterial and fungal spoilage
- Impacts of storage time, temperature, and humidity

It assists in the determination of key factors causing storage loss and the testing of effectiveness of new storage technologies.

C. Remote Sensing and ICT Tools

Current technologies like drones, GIS mapping, IoT sensors, and mobile apps are now employed to measure post-harvest loss at scale. These technologies can:

- Detect grain quality, moisture, and storage conditions
- Remotely monitor crop condition and loss
- Enable real-time decision-making and interventions

D. Participatory Rural Appraisal (PRA)

This qualitative method involves active participation of farmers in identifying, mapping, and estimating post-harvest losses. Farmers share their experiences, and tools like focus group discussions, matrix ranking, and seasonal calendars are used.

7. Post-Harvest Management Techniques

1. Harvesting

Harvesting is the initial and most crucial operation in post-harvest management. It must be executed at the appropriate stage of physiological maturity to maximize quality and yield. Premature harvesting leads to immature produce, but delayed harvesting can cause losses from shattering, fungal infection, or pest infestation. Mechanical injuries are minimized by using sharp, clean equipment to avoid bruising and opening wounds, which otherwise lead to post-harvest spoilage.

2. Drying

Drying is necessary to minimize the moisture level of produce to a storage-safe level. Sun drying on clean, raised platforms is the conventional method used extensively by farmers. But solar dryers provide a better and controlled process of drying, particularly in unfavorable weather conditions. The moisture content should be monitored prior to storage—the recommended moisture levels are around 12% for cereals and 10% for pulses. Satisfactory drying avoids mold development, aflatoxin infection, and infestation from insects.

3. Cleaning and Grading

Cleaning and grading are necessary after drying to enhance both market value and storage quality. Cleaning eliminates dust, foreign particles, and diseased or damaged produce. Grading consists of sorting the produce according to size, color, and quality requirement. It not only beautifies the produce for the consumer but also fetches higher prices in the market.

4. Packaging

Effective packaging keeps the produce safe from physical injury, pest attack, and climatic conditions. Jute bags, HDPE bags, or PICS bags are used for cereals and legumes. Ventilated crates and cushion boxes are used for fruits and vegetables. Proper labeling and handlings during packing also help minimize losses.

5. Storage

Scientific storage is important to maintain produce for extended periods. It comprises the utilization of proper storage units such as metallic bins, moisture-proof packets, or ventilated godowns. The internal climate should be checked on a regular basis for temperature and humidity. Fumigation or natural pest control should be applied to avoid damage due to insects, rodents, and fungi. Sanitation and aeration within storage units are also necessary.

6. Transportation

Transport is a weak link stage where much loss is experienced due to careless handling, bad roads, and overloading. To prevent losses, fruit should be transported in appropriate containers—plastic boxes for perishables, properly packed bags for grains. Cars should be clean, ventilated, and preferably temperature-controlled for delicate items. Eliminating long waits and undue loading/unloading minimizes physical damage and spoilage.

8. Government Interventions

1. FSSAI Rules for Food Safety Standards

FSSAI is responsible for guaranteeing food quality throughout the supply chain. FSSAI prescribes legal requirements for the handling, processing, packaging, labeling, and storage of food. Through enforcement of hygiene and safety practices, FSSAI reduces risks of contamination during post-harvest operations and ensures consumers' trust in farm products.

2. National Food Security Mission (NFSM)

The NFSM was initiated to raise the cultivation of rice, wheat, pulses, and other staples and incorporate post-harvest interventions. These involve assistance for mechanized threshers, seed processing, drying yards, and pest control measures. The mission tries to minimize post-harvest losses while maintaining food availability at the country level.

3. Gramin Bhandaran Yojana

This scheme encourages the establishment of scientific storage facilities in rural regions through capital investment incentives. Farmers and cooperatives can set up warehouses and godowns to store produce in a secure manner, avoiding post-harvest losses due to moisture, infestation, or rot. The scheme also allows farmers to store produce and sell it at a later point when prices are better in the market.

4. Operation Greens

Originally centered on Tomato, Onion, and Potato (TOP) crops, Operation Greens aimed to stabilize prices and foster value chain development. It facilitates cold storage, transport, and processing units so that post-harvest losses in such perishables are minimized. Financial assistance is offered for establishing integrated value chains from production up to consumption.

5. PM Formalization of Micro Food Processing Enterprises (PM-FME)

Under the Atmanirbhar Bharat Abhiyan, this scheme facilitates the modernization and formalization of micro food processing units. It aids small-scale entrepreneurs in terms of subsidies, capacity development, branding, and packaging. By enhancing food processing facilities as well as procedures, the PM-FME scheme indirectly impacts post-harvest losses as it increases shelf life and marketability.

9. Extension and Capacity Building 1. Training Programs for Farmers

Successful post-harvest management starts with the training of farmers. Regular training programs for best practices like scientific drying techniques, proper moisture management, and safe storage are conducted by extension agencies. These programs highlight how reducing post-harvest losses can help improve income and food security.

2. Utilization of New Technologies

Farmers are exposed to solar dryers, which facilitate hygienic and effective drying of pulses and grains. They are also trained in grain protectants and fumigation methods to avoid pest infestation and spoilage at storage.

3. KVK demonstrations

Krishi Vigyan Kendras (KVKs) are field-level interfaces for demonstrating post-harvest technology. Demonstration on a live basis enables farmers to comprehend handling practices, control of moisture, and equipment operation.

4. Provision of Tools and Kits

Extension services also assist farmers by providing moisture meters, hermetic storage bags, and packaging kits to enable them to adopt efficient and safe post-harvest practices.

10. Recommendations and Future Directions

- Embrace community storage facilities with scientific ventilation
- Support farmer cooperatives for mutual infrastructure
- Use digital tools such as mobile apps for post-harvest advisory
- Facilitate R&D in biodegradable packing and non-chemical storage
- Market linkages for timely procurement and processing

11. Conclusion

Post-harvest losses in major crops are a prime hurdle to attaining food security, import dependency reduction, and doubling farmers' income. With a systematic evaluation and emulation of advanced post-harvest technologies, we can reduce these losses considerably. A multi-stakeholder strategy that involves farmers, scientists, policy-makers, and extension workers is critical in redressing this challenge effectively. Not just a technological challenge, but also a social and economic imperative, post-harvest losses can be minimized. Increasing awareness, building capacity, and equipping farmers with the necessary tools and skills can make the agricultural industry more productive and resilient.

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AGRICULTURE BULLETIN
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Evaluating Farmer Satisfaction with e-Mandi Platforms

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e-Mandi platforms such as e-NAM are revolutionizing agricultural marketing by offering farmers smooth price discovery, increased market access, and quicker payments. This bulletin examines farmer satisfaction in terms of accessibility, trust, and economic returns. It addresses benefits, obstacles, and strategies for improvement and presents successful case studies. e-Mandis can considerably increase smallholder income, market efficiency, and rural economic development with robust policy support and technological innovation.

1. Introduction

Indian agricultural marketing has traditionally centered around physical mandis governed under the APMC Acts. The mandis have been central to providing price discovery, safeguarding farmers from exploitation, and enabling sale of produce. Nevertheless, the system has suffered from persistent issues over time, such as monopoly of intermediaries, absence of transparency in transactions, payment delays to the farmers, poor grading and quality determination facilities, and infrastructure bottlenecks. To overcome these limitations, the Government of India and some state governments have launched e-Mandi platforms, most prominently the National Agriculture Market (e-NAM). These platforms seek to electronically link physical mandis to an integrated online trading system, allowing farmers to access a larger set of buyers across geographies. By harnessing technology, e-Mandis are meant to enhance price realization, lower transactional costs, and foster a transparent, competitive, and efficient marketing ecosystem.

Farmer satisfaction is an essential factor to measure the usefulness and longevity of such online platforms. It varies based on the ease of using the platform, promptness of payment settlement, transparency of price, consistency of quality rating, and general confidence in the system. Satisfaction of the farmer means that the farmer will be willing to repeat usage of e-Mandi services and promote their advantages to colleagues, thus speeding up the adoption process.

This bulletin emphasizes analyzing farmer satisfaction with e-Mandi platforms in terms of operational efficiency, user experience, challenges, and policy support mechanisms that can further strengthen the digitalization of agricultural markets in India.

2. e-Mandi Platform Concept

An e-Mandi is an online agricultural marketing platform that allows farmers, traders, and consumers to communicate and exchange agricultural produce online. It is a contemporary alternative to traditional mandis through the use of digital technology within the marketing system for agriculture.

Key Components

Digital Interface: Internet-based portals and mobile apps for farmer registration, bidding, and safe online payments.

Market Integration: Connecting multiple Agricultural Produce Market Committee (APMC) mandis into one single national or state-level trading platform.

E-Trading Modules: Online auctioning platforms, real-time price discovery systems, and automated settlement systems.

Logistics Support: Warehousing space, transport coordination facilities, and quality testing facilities to ensure free flow of trade.

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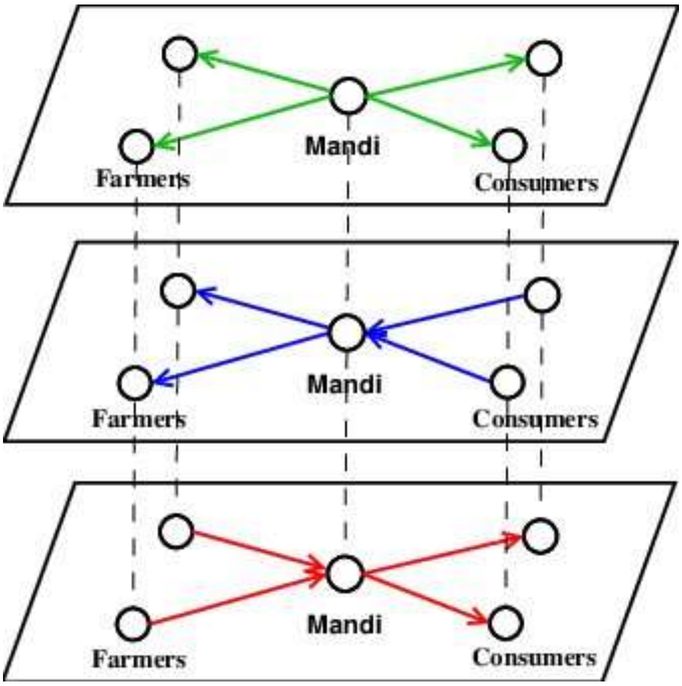

Source: https://www.researchgate.net

Core Functions

- Provides online bidding and transparent price discovery to avoid exploitation by middlemen.
- Provides inter-state and inter-mandi trade, providing farmers with access to more extensive markets.
- Reduces commission agent dependency by linking farmers to buyers directly.
- Provides quality certification, grading, and standardization of the product to establish trust with buyers.

Example

The National Agriculture Market (e-NAM) is India's biggest e-Mandi project, unifying more than 1,200 APMC mandis. With one digital platform, e-NAM allows farmers to offer produce for sale, get competitive bids from across the country, and finalize transactions online. It has enormously enhanced price realization, cut down transaction delays, and promoted transparency in agricultural transactions.

Source: https://blog.agribazaar.com

3. Benefits for Farmers

Benefit	Impact on Farmer Satisfaction
Transparent Price Discovery	Builds trust and reduces exploitation
Wider Market Access	Increases competition and better prices
Reduced Middlemen Dependence	More direct transactions and higher income
Digital Payments	Faster, more secure transactions
Quality Testing & Grading	Helps farmers fetch premium prices

Overall Impacts:

- improved Income: Competitive bidding tends to yield superior price realization.
- Access to Real-Time Information: Farmers are able to monitor demand and price trends prior to selling.

4. Drivers of Farmer Satisfaction

Farmer satisfaction with e-Mandi platforms is influenced by a set of enabling factors and lingering challenges that drive adoption, trust, and perceived value.

Positive Drivers:

Smartphone & Internet Penetration: Increasing smartphone penetration in rural regions, along with growing mobile internet penetration, facilitates farmers' convenient access to e-Mandi services.

Government Awareness & Training Programs: Activities like workshops, Krishi Vigyan Kendra (KVK) demonstrations, and farmer fairs have raised awareness regarding registration, bidding procedures, and advantages of e-trading.

Adoption of Digital Payments: The use of safe and instant digital payment systems instils trust, facilitating timely and transparent financial payments for produce sold.

Market Transparency: Transparent price discovery and online auctions minimize reliance on middlemen, allowing farmers to negotiate improved prices.

Barriers:

Digital Literacy Disparities: Less-educated or older farmers are likely to find it difficult to navigate the platform, lowering their involvement and efficiency in internet-based trading.

Connectivity Problems: Unstable or slow internet connectivity in rural villages may slow down participation in auctions or delay confirmations of payment.

Trust Deficit: Physical disconnection from buyers can generate payment safety concerns, equitable grading, and quality control fears.

Post-Sale Logistical Delays: Ineffective post-sale logistics, including poor transport services or unsuitable warehousing facilities, will dilute the apparent benefits of participating in e-Mandi.

5. Case Studies

Case Study 1 – Rajasthan e-Mandi Adoption

In the Kota district of Rajasthan, a series of specific training programs for farmers and digital literacy sessions enabled the enrollment of more than 3,000 farmers onto the e-NAM (Electronic National Agriculture Market) platform. These were jointly arranged by the state agriculture department and Krishi Vigyan Kendras (KVKs), with localized support in the local language. Agricultural producers were taught to register, list their products, and engage in online auctions. Consequently, the participants witnessed an average 12% price rise from compared to mandi transactions, mainly because of direct access to interstate buyers and decreased reliance on middlemen. Additionally, electronic payments to bank accounts increased transparency, lowered the risk associated with handling cash, and increased overall confidence levels in platform-based trading.

Case Study 2 – Maharashtra Onion Trade on e-Mandi

In Nashik, Maharashtra India's onion trading center farmers embraced e-Mandi platforms to sell in bulk during the peak season. The platforms gave real-time price signals through mobile apps and SMS, allowing growers to optimize sales timing for the best returns. The online bidding mechanism created chances to reach buyers from other states, improving market coverage. Payments were made and repaid within 48 hours, which dramatically enhanced cash flow for farmers and reduced their dependency on local commission agents for liquidity. Additionally, the digital record of transactions provided a way for farmers to analyze sales and develop plans or apply for loans. Overall, the experience helped raise repeat usage, though many farmers still favoured a hybrid approach for fear of internet failure or platform downtime.

6. Plan Improving Farmer Satisfaction

Improving farmer satisfaction with e-Mandi platforms involves a multi-pronged strategy focusing on both digital preparedness and operational effectiveness.

1. Capacity Building:

Hands-on, practical training exercises at Krishi Vigyan Kendras (KVKs) and Farmer Producer

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Organizations (FPOs) can fill the gap in digital literacy. Visualization exercises in registration, bidding, and digital payment processes instill confidence among users.

2. Localized Language Support:

To serve diversified rural communities, e-Mandi mobile apps must provide multi-language user interfaces and voice-guided navigation with local dialects. This increases the system's inclusivity for less literate users.

3. Hybrid Market Models:

A combination of online bidding with offline mandi verification makes the process transparent and helps establish credibility. Farmers are able to verify product quality in person while continuing to benefit from larger digital markets.

4. Improved Logistics:

Cooperation with warehouse providers, transport operators, and cold storage ensures efficient delivery and storage of produce. Real-time tracking can increase transparency and reliability.

5. Incentives for Early Adopters:

Providing incentives like forgone transaction fees, reward points, or listing priority for early registrants promotes participation as well as word-of-mouth.

7. Policy and Institutional Support

The success of e-Mandi platforms in heightening farmer satisfaction has a direct correlation with robust policy support and institutional enabling. The e-NAM Expansion Plan proposes bringing all Agricultural Produce Market Committees (APMCs) under one pan-national e-trading system so that farmers are able to access markets wider than their local mandis. As part of the Digital India Programme, the government is also focusing on better rural connectivity through the internet, so that even far-flung villages are able to join digital farming trade. In addition, subsidies for farmer digital literacy schemes are being launched with an emphasis on hands-on skills for navigating platforms, bidding online, and price checking. To build trust and ensure transparency, investment in quality infrastructure is currently being done, such as the establishment of grading, sorting, and testing labs in mandis. These efforts will help build a transparent, competitive, and farmer-friendly e-Mandi ecosystem that improves adoption rates as well as farmers' confidence.

8. Future Outlook

The future of e-Mandi platforms is to leverage emerging digital technologies to further augment farmer satisfaction, transparency, and profitability. Artificial Intelligence price forecasting software can give farmers predictive information on commodity price movements, allowing them to select the best time to market their produce for maximum profit. This will aid in minimizing distress selling and enhancing bargaining power. Blockchain technology can be integrated to ensure tamper-proof transaction records, establishing higher trust levels between buyers and sellers while ensuring payment settlement transparency. The interface with crop insurance schemes can enable automatic correlation of sales data with insurance claim settlement processing, accelerating compensation for crop loss and reducing paperwork. Moreover, IoT-based quality inspection systems can execute grading and sorting automatically through sensor-based mechanisms, eliminating human bias and enhancing standardization of fruit and vegetable quality. As such innovations are rolled out, e-Mandi platforms can become full-fledged agri-commerce platforms, not only for marketing produce but for offering market insights to farmers, financial services, and quality checks—ultimately making the agri-supply chain more efficient, equitable, and farmer-friendly.

9. Conclusion

e-Mandi platforms are transforming Indian agriculture marketing by making it more transparent, accessible, and farmer-centric. Farmer satisfaction is contingent on a mix of technological simplicity,

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market advantage, trust, and enabling infrastructure. Long-term success will depend on ongoing policy support, digital literacy initiatives, and adoption of latest technologies. Proper implementation can enable e-Mandis to revolutionize rural agricultural economies and empower small farmers.

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Krishi DSS and Voice-Based Advisory Uptake Among Rural Smallholders

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Krishi Decision Support Systems (DSS) and voice-based advisory services are revolutionizing smallholder farming by providing timely location-specific suggestions. DSS uses weather, soil, crop, and market information for accurate advice, and voice platforms bridge literacy and connectivity gaps by using local language communication. Collectively, they increase productivity, minimize risks, and enhance market access, providing a scalable route to technology-led, sustainable, and inclusive rural farming systems.

1. Introduction

Agriculture is the single major source of livelihood for most of India's rural inhabitants, with over 85% of farmers identified as smallholders holding less than two hectares of land. Though they play a very vital role in maintaining food security, smallholders are confronted with numerous challenges that include uncertain climatic conditions, regular pests and diseases infestations, uneven market prices, and limited access to timely and trustworthy advisory services. These limitations frequently lead to inefficient farm decisions, reduced productivity, and less stable incomes. Over the past few years, digital agriculture solutions have found their way as revolutionary instruments that have been capable of fulfilling these limitations. Among them are Krishi Decision Support Systems (DSS) and voice-based advisory platforms.

Krishi DSS integrates real-time data from various sources like weather forecasts, soil health data, crop growth models, and market price trends, and processes it via powerful algorithms to produce actionable, location-based recommendations. These advisories include vital issues like the best sowing date, irrigation scheduling, pest and nutrient management, and market timing.

Voice-based advisory services employ Interactive Voice Response Systems (IVRS), phone calls, and artificial intelligence-based virtual assistants to provide farmers with agricultural advice in their own local languages and dialects. This method is efficient in bridging literacy divides, making it inclusive, and particularly useful in regions with low smartphone penetration or poor internet coverage.

Through the coupling of science-driven suggestions with simple modes of communication, Krishi DSS and advisories via voice can enable smallholders to make timely and knowledge-based decisions, minimize production risks, enhance farm profitability, and increase resilience towards climate and market vagaries.

Source: https://www.vajiraoinstitute.com

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2. Concept of Krishi DSS

A Decision Support System (DSS) in agriculture is an information technology-based system intended to support farmers in making timely and informed decisions by analyzing varied agricultural data and translating it into actionable, farmer-usable advice. It acts as a platform to connect involved scientific complexities and actual agricultural practices at the farm level, making the advice relevant, actionable, and site-specific.

Key Components:

Data Sources: Inputs are obtained from various sources including short- and long-term weather forecasts, soil health card information, crop growth simulation models, remote sensing images, and current market price trends.

Analytics Engine: Sophisticated algorithms, Artificial Intelligence (AI), and Machine Learning (ML) models are utilized to process these datasets and forecast best farming activities for a given crop and location.

User Interface: Recommendations are communicated through farmer-friendly media like mobile apps, web interfaces, voice calls, or SMS, making it available to all levels of literacy and connectivity.

Core Functions:

Recommendation for appropriate crops to grow on the basis of climate and soil type

- Recommendation of best sowing time and planting method
- Timing irrigation to ensure maximum water efficiency
- Supplying fertilizer and nutrient management plan on the basis of soil test values
- Giving warning for impending pest and disease attack
- Providing market linkages guidance for enhanced price realization

Example: The Krishi Decision Support Platform, designed by ICAR together with State Agricultural Universities and agri-tech start-ups, is an example of a good initiative that provides integrated advisories for enhanced farm management and sustainable productivity.

3. Voice-Based Advisory Services

Voice-based advisory services are being developed as an essential mode of communication for rural smallholders, especially those with poor literacy and digital competence. Differing from text or app-based advisories, voice-based systems communicate agricultural information in a natural conversational form that is easier for farmers to comprehend and implement.

Why Voice?

- Towards about 32% of rural households possess poor literacy, so text-based advisories will not be effective.
- Though mobile internet penetration is on the rise, network coverage is still patchy in rural villages, making high-data applications inaccessible.
- Local language and dialect delivery guarantees that farmers are able to understand and believe the information presented.

Delivery Modes:

Outbound Voice Calls (Push-Based): Robocalls offer imperative notifications like weather, pest or disease outbreaks, and market prices.

IVRS Hotlines (Pull-Based): Interactive Voice Response Systems enable farmers to call a number and go through menus to hear particular advisories on crops, livestock, or government schemes.

Chatbots & AI Assistants: Platforms such as smart speakers or WhatsApp voice notes provide interactive, on-demand guidance, usually augmented with AI for personalization.

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Example Platforms:

Kisan Call Centre (KCC): Countrywide helpline providing expert advice in various languages.

IFFCO Kisan IVR Service: Offers market, weather, and agronomic information to subscribers.

Krishi Sarthi Voice Advisory: Offers localized, crop-oriented advisories through voice messages and expert advice.

4. Benefits for Rural Smallholders

Both voice-based advisory services and Krishi DSS provide unique and complementary advantages to rural smallholder farmers. Whereas DSS platforms are more analytical and data-intensive, voice advisories are better at accessibility and inclusivity.

Comparative Benefits:

Benefit	Krishi DSS	Voice Advisory
Timely Decisions	✓	✓
Local Language Support	Limited	High
Personalization	High	Moderate
Overcomes Literacy Barrier	No	Yes
Data-Driven	Yes	Limited

Overall Impacts on Smallholders:

Enhanced Yield: Seasonal advice regarding sowing time, seed choice, fertilizer applications, and pest control allow the farmer to optimize production.

Minimized Losses: Pre-warnings by DSS regarding pest and disease infestation and voice alerts regarding adverse weather conditions reduce crop loss and input utilization.

Optimized Market Price Receipt: Market information through DSS and price updates via voice alerts enable farmers to select best selling times and places.

Improved Resource Efficiency: DSS-driven irrigation timetables and fertilizer management regimes prevent water and fertilizer loss, while voice reminders provide timely application.

Improved Inclusivity: Voice-based solutions extend vital agricultural information to even the most disadvantaged farmers, such as women and elderly farmers, who are unlikely to use text-based applications.

5. Factors Influencing Uptake

The uptake of Krishi DSS and voice-based advisory services among rural smallholders is informed by a mix of empowering drivers and hard-hitting constraints. It is crucial to comprehend these drivers and constraints in order to develop strategies that optimize farmer engagement and sustained use.

Positive Drivers:

Smartphone Penetration: Rural smartphone penetration has hit around 67% by 2024, allowing for more farmers to access voice-based services and DSS applications.

Mobile Network Rollout: Constant expansion of 4G/5G coverage and low-cost data plans has hugely enhanced rural connectivity, rendering real-time advisories more dependable.

Government and NGO Schemes: Initiatives under the National e-Governance Plan in Agriculture (NeGPA), Digital India, and other NGO initiatives are enthusiastically spreading awareness and capacity building for digital farming applications.

Barriers:

Low DSS Feature Awareness: Most farmers are not aware of the way DSS operates, and view it as complicated or not relevant to their short-term needs.

Lack of Trust: Farmers tend to use traditional knowledge, peer recommendations, or local extension people, and thus do not see the need to substitute or complement these with computerized advisories.

Language and Cultural Compatibility Issues: DSS websites at times do not integrate content at local language levels, idioms, and farming tradition, thus curbing relevance.

Cost and Device Compatibility: Subscriptions or the requirement of high-end smartphones can discourage uptake, particularly among fringe farmers who have limited disposable income.

6. Case Studies

Case Study 1: Maharashtra Cotton DSS

Farmers in Maharashtra's cotton belts have been employing an AI-driven pest alert system that comes with a Krishi DSS platform. The technology weaves together real-time field inputs from pheromone traps, weather forecasts, and crop growth models to forecast pest infestations, specifically Helicoverpa armigera and pink bollworm. Farmers are alerted by mobile apps and SMS, instructing them on the best time for applying pest control measures.

Impact: Implementation of this system resulted in 18% reduction in pesticide usage, reducing input costs and environmental burden. Concomitantly, improved intervention timing yielded a 14% increase in yield. This example indicates how precision DSS can enhance profitability and sustainability at the same time.

Case Study 2: Bihar Voice-Based Weather Advisory

Bihar has a voice-based advisory service based on IVRS providing rainfall forecasts, temperature indices, and crop-specific advice. Push calls are made to farmers at crucial growth stages, and they can also call a hotline to receive custom advice in local language.

Impact: In one assessment, 62% of the participating farmers changed their irrigation schedules according to these advisories. This resulted in appreciable water savings during times of drought and saved irrigation costs. The farmers also experienced improved crop stand and less lodging when rains came unexpectedly.

These case studies illustrate that data-intensive DSS and voice-based services accessible to everyone can have tangible positive impacts if they are localized. The trick is in making scientific precision meet user-friendly communication channels so that adoption is widespread and benefits to smallholder farmers can be realized.

7. Strategies to Enhance Adoption

For Krishi DSS and voice advisory services to be widely adopted by rural smallholders, solutions must overcome both technical and socio-cultural issues while fostering trust and usability.

1. Localization: Voice advisories and DSS advice must be customized to district- and block-level agro-climatic conditions. Local cropping patterns, soil profiles, and seasonality need to be integrated into advice to make it extremely relevant and actionable.

2. Language Support: Providing advisories in native dialects with easy, jargon-free language facilitates greater inclusivity. For voice-based services, using known accents and expressions enhances farmer participation and credibility.

3. Hybrid Models: Merging DSS-computed advice with onsite visits by extension workers can enhance credibility. Demonstrations, on-farm trials, and follow-up visits can strengthen the adoption of recommended practices.

4. Capacity Building: Training sessions through Krishi Vigyan Kendras (KVKs), Farmer Producer

Organizations (FPOs), and cooperatives could enhance farmers' digital literacy. Group training in the use of mobile apps, interpretation of DSS outputs, and reacting to voice advisories can make learning faster.

5. Public–Private Partnerships: Joint efforts by government departments, research institutions, and agri-tech start-ups can bring together resources and expertise. Whereas public departments provide wide reach and credibility, start-ups offer innovation, speed, and sophisticated analytics.

8. Policy and Institutional Support

Strong policy and institutional backing underpin the successful scaling up of Krishi DSS and voice-based advisory services. Various government schemes and initiatives in India are actively facilitating the integration of digital technology into agriculture.

Digital India Programme: This flagship program is augmenting rural broadband, mobile network coverage, and internet affordability. Better digital infrastructure is the foundation for smooth operation of both DSS platforms and voice-based advisory systems.

National e-Governance Plan in Agriculture (NeGPA): NeGPA encourages the utilization of ICT in agriculture by means of projects that computerize agricultural databases, facilitate mobile-based advisory services, and provide interoperability among various digital platforms. This allows easier integration of DSS tools with current government services.

Pradhan Mantri Fasal Bima Yojana (PMFBY): With PMFBY, DSS technologies are being utilized more for precise and timely crop loss estimation. Satellite imaging, weather information, and remote sensing are brought into decision-making, making insurance claim settlements faster and more transparent.

Incentives for Agri-Tech Start-ups: Government, under schemes such as Agri-Infra Fund and Start-up India, is providing grants, tax relief, and incubation facilities to companies working to establish voice-based advisory systems, AI-based DSS tools, and rural digital extension platforms.

9. Future Outlook

The future of Krishi DSS and voice-based advisory services will be determined by accelerating digital technology advancements, higher levels of integration of real-time data, and increased personalization emphasis for smallholder farmers.

AI-Powered Chatbot Integration: AI-driven conversational interfaces will turn advisory services into more engaging and interactive experiences. Farmers will be able to pose queries in their local language and receive immediate, context-relevant advice. Such chatbots can be run through mobile applications, WhatsApp, or even voice-enabled speakers, making them a multi-platform offering.

IoT Sensor Interconnection for Automatic DSS Updates: Interconnecting DSS platforms with in-field IoT devices like soil moisture sensors, weather stations, and crop health monitors will facilitate real-time, automatic updates. It will eliminate manual data input and ensure that recommendations are more accurate.

Predictive Analytics for Climate Resilience: Sophisticated predictive models will assist in anticipating extreme weather occurrences, pest infestations, and water supply, allowing farmers to take early preventive measures well beforehand. Such tools will be invaluable in coping with the effects of climate change.

Blockchain-Enabled Market Advisory: Blockchain technology can make price discovery more transparent by recording market transactions in a secure and tamper-proof manner. Farmers could receive trustworthy market rates and direct buyer connections, reducing dependency on middlemen.

10. Conclusion

Krishi DSS and voice-based advisories are revolutionizing smallholder decision-making through timely, personal, and accessible agriculture advice. Their effectiveness will hinge on localization, affordability, trust-building, and harmonization with conventional extension services. With continued policy support, these technologies have the potential to dramatically enhance rural livelihoods and agricultural productivity.

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New Paths for Tribal Farmers: How FPOs are Changing Lives

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Across the rural expanse of India, especially in the tribal-dominated and ecologically fragile regions of central and eastern India, a quiet yet transformative revolution is underway. Small and marginal farmers particularly tribal millet cultivators, who have long depended on subsistence farming with minimal external support, are now organizing themselves through Farmer Producer Organizations (FPOs) (SFAC, 2022). Tribal population are scattered all over the hilly and forest regions of the country, majority of them inhabitants in Central India, high concentration of tribal's live in Madhya Pradesh, Chhattisgarh, Orrisa, Andhra Pradesh, Jharkhand (Rajan et al. 2015). These farmer-owned, farmer-led institutions are bridging systemic gaps in input supply, credit, processing, and marketing, leading not just to better farm incomes but to social empowerment and economic dignity for some of the country's most underserved agricultural communities (NABARD, 2023).

The revitalization of these "nutri-cereals" through FPOs is restoring both nutritional security and commercial viability to forgotten crops (ICAR-IIMR, 2022; FAO, 2023). The declaration of 2023 as the International Year of Millets by the United Nations, with India as the lead promoter, has further spotlighted the economic potential of tribal millet growers when supported by structured, collective platforms like FPOs (FAO, 2023; MoA&FW, 2021). This movement reflects the Government of India's mission to double farmers' income and promote inclusive, sustainable and climate-resilient agriculture, especially in tribal regions that are rich in biodiversity but poor in infrastructure. With millets such as Kodo and Kutki being traditional staples in tribal areas, these "Nutri-Cereals" have been integral to India's dietary traditions due to their cultural, nutritional and climate-resilient characteristics (Misra et al., 2021). The top millet-producing states include Rajasthan, Uttar Pradesh, Maharashtra, Karnataka, Gujarat and Madhya Pradesh.

The Struggles of Tribal Millet Farmers: A Background

Tribal millet farmers, particularly those in regions like Madhya Pradesh, Odisha and Chhattisgarh, confront a web of structural and socio-economic challenges that hinder their productivity and income potential:

- **Marginal Landholdings**: A significant majority of tribal farmers operate on less than 1 hectare of land, making them marginal cultivators. These fragmented and often sloped lands limit economies of scale, reduce mechanization opportunities and make commercial viability a challenge
- **Lack of Irrigation and Inputs**: Rainfed agriculture accounts for over 85% of millet cultivation in tribal areas, making it highly vulnerable to monsoon variability. Moreover, access to certified seeds, organic fertilizers and extension services remains poor, leading to low yields (Rajan et al., 2016).
- **Poor Market Access**: Many tribal villages are situated far from regulated agricultural markets (mandis). In the absence of infrastructure and transport, farmers are compelled to sell their produce to local traders or middlemen at exploitative rates,

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often 30–40% below MSP (NABARD, 2023; SFAC, 2022).

- **Limited Financial Resources**: Formal financial inclusion among tribal farmers is low. Without access to institutional credit, they are frequently dependent on private moneylenders who charge exorbitant interest, trapping them in cyclical debt.
- **Post-Harvest Losses**: Due to inadequate storage facilities and lack of community-level processing units, tribal farmers suffer significant post-harvest losses. Studies estimate that up to 15–20% of millets are lost or degraded before reaching markets (ICRISAT, 2022).
- **Low Awareness and Information Access**: Tribal farmers often remain unaware of government schemes, pricing policies or the commercial and nutritional value of millets. This information asymmetry reduces their ability to negotiate fair prices or explore value addition.

What is an FPO? Why is it Revolutionary?

Farmer Producer Organization (FPO) is a registered group of farmers who come together to collectively perform various agricultural and business activities, including input purchase, crop planning, marketing, processing and export. FPO is typically a society or company consisting of farmers who are actual producers of specified commodities. These organizations are registered under the Mutually Aided Cooperative Societies (MACS) Act 1995 or as a Farmers Producer Company (FPC) under the Companies Act 2013. FPOs are formed at cluster, block, district or state levels depending on the needs of producers and the demand potential, with a value chain approach to enhance economic and social benefits for farmers (Sangappa and Rafi, 2023).

Government agencies like SFAC (Small Farmers' Agribusiness Consortium) and NABARD (National Bank for Agriculture and Rural Development) have been instrumental in supporting FPOs through funding, training and policy support, particularly targeting marginalized communities. As of 2023, over 10,000 FPOs were operational in India, with at least 3,000+ focusing on tribal or backward areas (SFAC, 2023). The Government of India has launched a Central Sector Scheme for Formation and Promotion of 10,000 FPOs (2020–2025) with a budget of ₹6,865 crores to support these efforts. (MoA&FW, 2021).

How FPOs Empower Tribal Millet Growers

- **Economic Empowerment through Better Market Access**

Tribal millet farmers often lack access to proper markets and are forced to sell at low prices. FPOs aggregate produce, enabling bulk sales to large buyers like retailers and exporters. This collective approach increases bargaining power, fetches better prices and reduces dependency on middlemen.

- **Reducing Cost of Cultivation**

FPOs procure seeds, fertilizers and equipment in bulk and supply them at reduced prices to members. This significantly cuts production costs. They also encourage eco-friendly farming practices using indigenous seeds and organic inputs, improving sustainability and yield.

- **Knowledge and Skill Empowerment**

FPOs regularly organize training through KVKs and NGOs to educate farmers on improved farming techniques, soil health, water management and pest control. This helps tribal farmers adopt modern, effective practices and boosts their confidence to innovate in agriculture (Sarkar et al., 2022).

- **Access to Credit and Government Support**

Many tribal farmers lack formal credit history and rely on moneylenders. FPOs help them open bank accounts, access crop loans, and insurance and

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government subsidies. With proper guidance and documentation, farmers are empowered to become financially independent.

- **Post-Harvest Handling and Value Addition**

FPOs set up small processing units to cleaning, de-husking and milling millet. They also support packaging, branding and direct marketing. This allows farmers to earn two to three times more by selling processed and branded millet products rather than raw grain.

- **Social Empowerment and Women's Participation**

FPOs encourage active participation of tribal women through SHGs, processing work and leadership roles. This not only enhances household income but also strengthens women's role in decision-making, fostering gender equity in rural communities.

The Millet Advantage: Why This Crop Deserves More

Millets, often termed as *"nutri-cereals,"* are traditional crops cultivated by tribal communities from centuries. They include Kodo, Kutki, Ragi, Bajra and Jowar.

Benefits of millets:

- *Highly nutritious:* Rich in fiber, iron, calcium and magnesium
- *Climate-resilient:* Grows in drylands, needs minimal water
- *Pest-resistant:* Requires fewer chemical inputs
- *Ideal for organic farming*
- *Long shelf life*

The global recognition of millets grew after the *UN declared 2023 as the International Year of Millets,* bringing international attention to these humble grains.With proper support from FPOs, tribal millet growers can ride this wave of growing health consciousness and achieve higher incomes through quality and branding.

Chhindwara's Tribal Millet FPOs: A Case Study

Chhindwara, a predominantly tribal district in Madhya Pradesh has several millet-based FPOs supported by government and NGO partnerships. One such FPO began in 2019 with 110 tribal members growing Kodo and Kutki millets. Over four years, the FPO grew to 300 members, procured machinery for de-husking and packaging, created a brand called ***"Adivasi Anaj"*** to market millets as organic tribal-grown produce and linked with health stores in Bhopal and Nagpur.

The Impact

- Farmers' income doubled from ₹15,000/year to ₹35,000–₹50,000
- Women-led groups started millet snacks and home-based food businesses
- Seasonal migration dropped, as families began earning from local produce

This transformation showcases how FPOs can anchor development from within the community.

Millet Processing Center situated at Tamia Block of Chhindwara District

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Voices from the Ground: Changing Lives

Meena Bai – A Journey from Margins to Market

Meena Bai, a tribal woman from a village near Tamia block, used to sell millets for ₹10/kg to local traders. With the help of her FPO, she learned organic farming, improved packaging and began selling millet laddoos under a local women's brand. Today, she earns over ₹50,000 annually and trains other women in her group.

"*I used to feel invisible. Now people know me. I earn with pride," she says.*

Suresh Dhurve – A Young Farmer's Innovation

Suresh, a 25-year-old tribal youth, uses WhatsApp to share daily prices and weather updates among FPO members. He encourages youth to adopt millet farming and participate in marketing decisions.

"*These are not just grains, they are our future," he says.*

Challenges on the Road Ahead

Despite significant progress, several challenges remain:

1. *Lack of trained leadership:* Many FPOs struggle with bookkeeping, compliance and market strategy.
2. *Financial dependence:* Some rely too heavily on donor funding and need sustainable business models.
3. *Limited processing infrastructure*
4. *Inadequate cold chains or transport*
5. *Regulatory hurdles and slow fund disbursement*

Addressing these issues through regular training, digital tools and collaborative partnerships is vital for long-term impact.

The Way Forward: Supporting Tribal FPOs

To amplify the success of tribal millet FPOs, we need:

- Stronger policy support from central and state governments
- Public-private partnerships for infrastructure, processing and market access
- Dedicated credit schemes for tribal FPOs
- Training and incubation centres for youth and women entrepreneurs
- Branding campaigns to popularize tribal millets nationally and globally

Conclusion: Planting Seeds of Prosperity

The story of FPOs and tribal millet growers is not just about income it is about **identity, resilience and transformation**. By organizing collectively, accessing modern tools and reviving traditional knowledge, tribal communities are rewriting their future on their own terms. FPOs have proven to be more than economic entities. They are **agents of social change**, bringing dignity to the fields and power to the farmers. As we move toward sustainable and inclusive agriculture, tribal FPOs must be

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nurtured and scaled as **pillars of rural development**. The humble millet, when grown together and sold smartly, can become the grain of hope, health and holistic progress.

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Role of Precision Horticulture in Enhancing Productivity and Resource Use Efficiency

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1. Introduction

Precision horticulture is a cutting-edge, technology-based strategy for horticultural crop production with an accent on site-specific management of resources and cultivation techniques. It encompasses the use of novel tools and technologies like remote sensing, geographic information systems (GIS), soil and crop sensors, automation systems, and sophisticated data analytics. Through gathering and interpreting real-time information, precision horticulture allows farmers to make decisions that maximize crop yield, enhance quality, and guarantee optimal usage of resources. The practice not only increases productivity but also helps to reduce the environmental footprint and enhance sustainability in horticultural production systems.

2. Major Goals of Precision Horticulture

Optimizing Productivity

Precision agriculture strives to attain greater yields while at the same time improving produce quality. By implementing inputs in the right amount, at the correct time, and in the correct location, farmers can position plants in the best conditions for growth and development, resulting in superior marketable produce and profitability.

Improving Resource Use Efficiency

The strategy emphasizes minimizing wastage of valuable resources like water, fertilizers, and pesticides. Technologies such as drip irrigation, fertigation, and precision spraying provide for the application of inputs where and when they are essential, conserving inputs and reducing the costs of production.

Minimizing Environmental Footprint

By minimizing the use of inputs and curtailing unnecessary use of agrochemicals, precision horticulture avoids problems such as soil erosion, water contamination, and loss of biodiversity. This renders the production system more sustainable and eco-friendlier in the long term.

Facilitating Data-Driven Decision-Making

Precision agriculture uses real-time information gathered from sensors, drones, satellite photography, and automated systems to inform farm management decisions. The data-driven insights enable farmers to react quickly to crop stress, pest outbreaks, nutrient gaps, or irrigation requirements, resulting in timely intervention and improved overall crop health.

3. Key Elements of Precision Horticulture

Remote Sensing and Geographic Information Systems (GIS)

These technologies are applied for monitoring plant health, soil heterogeneity, and water stress in large areas. High-resolution satellite imagery or aerial photography is used to detect spatial variation within the field, allowing for site-specific management.

Soil and Plant Sensors

Modern sensors monitor key parameters like soil moisture, nutrient levels, pH, electrical conductivity, and microclimate status near the crop canopy. These real-time data enable accurate irrigation and fertilization planning.

Variable Rate Technology (VRT)

VRT enables the use of inputs like fertilizers, pesticides, and irrigation water in different quantities

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in different parts of the field depending on the particular requirements of the respective zones. This optimizes resource use and reduces wastage.

Automated Irrigation Systems

Drip and micro-irrigation systems, combined with soil moisture sensors and weather information, enable automated and need-based water supply. Scheduling based on sensors prevents over-irrigation and water stress.

Drones and Unmanned Aerial Vehicles (UAVs)

Multispectral and thermal cameras attached to drones deliver high-resolution images to spot infestations of pests or diseases, measure canopy density, and identify plant growth patterns. Based on this information, interventions for crop care can be given specifically.

Decision Support Systems (DSS)

AI and machine learning–driven models process data gathered to forecast yield, identify stress, and suggest best management practices. These systems improve the accuracy and speed of decision-making.

4. Contribution of Precision Horticulture to Increasing Productivity

Early Identification of Crop Stress

Precision technologies help identify deficiencies in nutrients, attacks by pests, disease infections, and water stress early on. Farmers can thus immediately institute corrective measures, minimizing yield losses.

Optimized Use of Inputs

By using water, fertilizers, and pesticides when and where needed, precision horticulture provides well-balanced nutrition to the crops and supports improved growth at lower input costs.

Uniform Crop Stand

Field variability management by adopting site-specific practices ensures plants from across the field grow uniformly, leading to consistent yields and better quality.

Improved Post-Harvest Quality

Tracing crop maturity indices and environmental factors allows for timely harvesting at optimal quality. This not only maximizes market value but also minimizes post-harvest losses.

5. Precision Horticulture Application for Enhancing Resource Use Efficiency

Water Efficiency

Precision horticulture facilitates the application of sensor-based drip and micro-irrigation systems providing water to the root zone of the plant in the desired amount and at the appropriate time. It has the potential to conserve 30% to 50% of water as compared to traditional flood irrigation and decrease evaporation and runoff losses.

Fertilizer Efficiency

Through variable rate technology and real-time nutrient sensing, fertilizers are applied where and when they are required and in exactly the amounts needed. This eliminates over-fertilization, reduces the leaching of nutrients into groundwater, and gives plants only balanced nutrients for maximum growth.

Energy Savings

Automated irrigation, fertigation, and crop monitoring systems greatly decrease the amount of labor needed and the time spent operating pumps and machinery. This results in energy conservation and decreased production costs.

Sustainable Land Use

Computer-based cultivation practices avoid soil compaction, salinity, and resource overexploitation. Through the reduction of excessive use of

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agrochemicals and soil health preservation, precision horticulture promotes sustainable and long-term land productivity.

6. Benefits of Precision Horticulture

Increased Profitability

Precision technologies translate into higher yields, better produce quality, and lower input expenses. This collective effect directly translates into farm profitability and market competitiveness.

Sustainable Farming Practices

By reducing wastage of resources and damage to the environment, precision horticulture supports sustainable agriculture. Reduced chemical use, optimal water management, and conservation of soil ensure that ecosystems are conserved for the next generation.

Improved Adaptation to Climate Change

Real-time tracking and predictive analysis allow farmers to act quickly in response to weather volatility, pest attacks, and disease threats. This adaptive ability is essential for sustaining productivity under conditions of climate change.

7. Challenges in Adopting Precision Horticulture

Although precision horticulture has huge potential, its large-scale adoption is hindered by numerous unresolved challenges:

High Initial Investment

The price of purchasing sophisticated technologies like drones, sensors, automated irrigation equipment, and decision-support software is usually high. For marginal and small farmers, it could prove to be an enormous deterrent in the absence of proper financial assistance or subsidies.

Lack of Awareness and Technical Expertise

A majority of the farmers lack knowledge about the principles and advantages of precision horticulture. Furthermore, there might be a lack of technical know-how for running modern machines and processing digital data.

Poor Infrastructure and Connectivity

Rural regions tend to experience poor internet connectivity, less reliable power supply, and fewer technical service providers. These issues can limit the use of IoT devices and cloud-based decision support tools.

8. Way Forward towards Promoting Precision Horticulture

To comprehensively utilize the potential of precision horticulture, a multi-faceted approach is required:

Promoting Awareness and Capacity Building

Conducting farmer training sessions, demonstrations, and workshops can increase awareness and capability in effectively utilizing precision technologies.

Developing Affordable and Scalable Technologies

Agri-tech enterprises and research institutions should work towards developing low-cost, easy-to-use precision horticulture equipment that can be tailored to different crops and farm sizes.

Integrating Advanced Digital Technologies

Integration with Internet of Things (IoT) devices, Artificial Intelligence (AI), and blockchain can enhance real-time tracking, predictive analysis, traceability, and value addition in the horticulture supply chain.

Fostering Government Incentives and Collaborations

Subsidies, low-interest loans, and policy incentives can boost adoption. Public-private partnerships (PPP) can further enhance infrastructure development, technology transfer, and market connections.

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9. Conclusion

Precision horticulture is a revolutionary method of horticultural crop cultivation, providing a route towards greater productivity, better quality, and effective use of inputs. Through the facilitation of site-specific management, real-time decision-making, and eco-friendly cultivation techniques, it serves both economic and environmental ends. It will be necessary, however, to overcome obstacles in the forms of high initial investment costs, farmer awareness deficits, and infrastructural limitations in order to achieve massive adoption. With robust support from policies, farmer-friendly training initiatives, and precision tool development at affordable costs, precision horticulture can redefine the future of sustainable horticulture not only in India but also across the globe.

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Assessment of Key Crops in Streamlining Post-Harvest Crop Handling

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Post-harvest losses directly affect food security and farmer revenues globally. This review examines the major crops such as cereals, pulses, fruits, vegetables, and oilseeds to determine particular post-harvest problems and efficient handling practices. Knowing the characteristics of the crops like moisture content, perishability, and susceptibility to insects, customized interventions like proper harvest timing, drying, packaging, storage, and transport can be adopted. Optimization of post-harvest handling by scientific means and technology minimizes quantitative and qualitative losses, improves shelf life, and facilitates marketability. This is essential for sustainable agriculture, which maintains food availability while making farmers more profitable.

Introduction

Post-harvest crop handling is an important stage in the value chain of agriculture, encompassing the process and methods employed in handling crops at the time of harvest in order to preserve their quality, minimize losses, and enhance market value. Streamlining post-harvest handling is crucial for increasing food security, minimizing economic losses, and improving the welfare of farmers, particularly in developing nations. Various crops need unique post-harvest handling approaches depending on their physical and biological properties. This bulletin aims to evaluate major crops and optimal practices to maximize post-harvest handling.

Importance of Post-Harvest Crop Handling

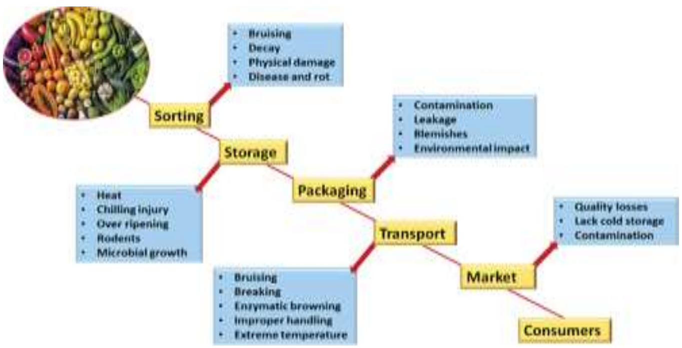
Post-harvest losses all over the world account for around 20-30% of overall agricultural output, amounting to an immense loss of food and income. Post-harvest losses are caused by improper harvesting methods, failure to process in time, poor storage facilities, insect infestation, mechanical injuries, and inefficient transport.

Rationalization of post-harvest handling has the advantages of:

- Reducing quantitative and qualitative losses
- Preserving nutritional value
- Increasing shelf life and marketability
- Improving food safety
- Enhancing farmer income and alleviating poverty

Assessment of Key Crops

Every crop possesses specific post-harvest needs. It is imperative to know their physiological characteristics to develop efficient handling operations. Hereafter, we present the major crops commonly grown in India and other tropical countries.



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Post-Harvest Handling of Cereals and Pulses

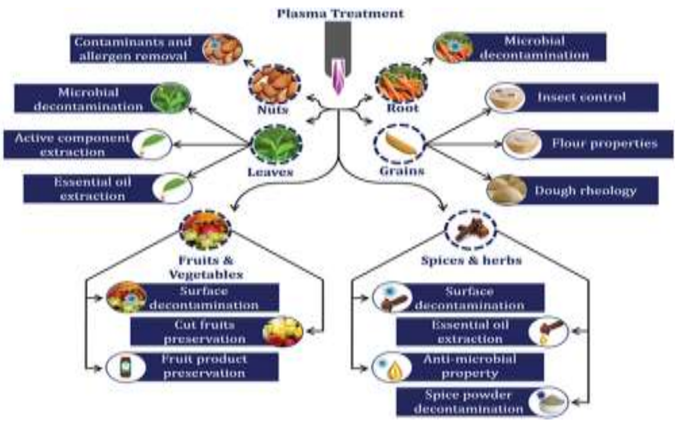
1. Cereals (Wheat, Rice, Maize):

Grains are usually of low moisture at harvest, at 12-14%, and have hard seeds. But in case the level of moisture is high, such grains are prone to fungal infection, leading to spoilage as well as health risks. Some of the post-harvest problems common in grains are shattering of grain at harvest, storage infestation by insects, and mold due to excessive moisture or inadequate ventilation.

In order to cope with these issues, cereals must be harvested at physiological maturity to achieve maximum grain quality and minimize losses. Post-harvest drying is imperative to bring down the moisture content of the grains to below 12%, which prevents the growth of fungi and insects. Safe storage follows; the use of tight, rodent-proof structures like silos or hermetic bags keeps the grains free from insects and external moisture. Regular observation for evidence of pests and fungal growth in storage facilitates interventions at the right moment, avoiding major quantitative and qualitative losses.

2. Pulses (Chickpea, Lentil, Mungbean):

Pulses are slightly more moist at harvesting and are prone to mechanical injury. The same handling practices early harvest, proper drying, soft threshing, and pest-resistant storage are needed to preserve pulse quality and shelf life.



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3. Post-Harvest Handling of Fruits (Mango, Banana, Citrus, Apple)

Fruits like mango, banana, citrus, and apple contain high water content and are thus extremely perishable. These fruits are also very sensitive to mechanical injury such as bruising, which hastens spoilage. These fruits also respire very fast, causing fast ripening and senescence. Post-harvest problems that often occur include microbial spoilage, loss of weight due to moisture evaporation, and uneven ripening, which all decrease fruit quality and market value.

In order to preserve fruit quality, harvesting at the right stage of maturity is essential. Too early or too late harvesting will impact flavor, texture, and shelf life. On-the-spot pre-cooling or icing during harvest slows down the metabolism and respiration rate of the fruit, thus prolonging freshness. Cushioned packaging materials for handling and transport prevent physical damage and bruising of fruits.

For extended storage, controlled atmosphere (CA) storage is utilized, where temperature, humidity, and gas composition (oxygen, carbon dioxide levels) are precisely controlled in order to retard respiration and defer ripening. Post-harvest treatments like waxes or use of registered fungicides also shield fruits from microbial infections, prevent loss of moisture, and enhance appearance, thereby increasing shelf life and consumer acceptability.

4. Vegetables (Tomato, Potato, Onion, Carrot)

Root vegetables like potato, onion, and carrot are very perishable with wide moisture levels and respiration rates, and they affect their storage life and shelf life. Typical post-harvest problems are wilting through water loss, rot through microbial infection, sprouting in potatoes, and sunburn injury in the exposed produce. Proper handling starts from harvesting at the right maturity for the highest quality and shelf life. Following the harvest, grading and sorting assist in eliminating damaged or diseased vegetables to avoid spreading the spoilage to healthy produce. Temperature- and humidity-controlled storage, for instance, cold storage for potatoes and onions, retards respiration and retards deterioration. Ventilated packaging is essential to prevent moisture accumulation and condensation, facilitating rot. Further, the application of anti-sprouting chemicals to potatoes during storage prevents unnecessary sprouting, maintaining their marketability as well as nutritional quality.

5. Oilseeds (Groundnut, Soybean, Sesame)

Oilseeds such as groundnut, soybean, and sesame are of moderate to high oil content and therefore prone to rancidity if they are not properly dried and stored. Excessive moisture fosters mold growth and enhances the chances of aflatoxin infestation, a severe health risk. Oil oxidation during storage also leads to seed degradation and loss of oil value.

To avoid such problems, drying is crucial to bring moisture levels below 8%, considerably hindering microbial growth and enzymatic processes. Drying storage facilities free from humidity and pests are critical to seed quality preservation. Frequent checking of stored seeds facilitates the detection and removal of infested and moldy lots to avoid contamination spread. Hermetic storage bags are an effective method for minimizing oxygen exposure, thus curtailing fungal development and oxidation, and extending seed viability and oil quality.

Methods for Simplifying Post-Harvest Handling

Simplification of post-harvest handling is necessary in order to minimize losses, ensure crop quality, and enhance farmer profitability. Successful management calls for scientific and technological interventions throughout the different stages following harvesting. The following are important techniques to maximize post-harvest handling:

1. Harvest Timing and Methods

Physiological maturity is important to harvest crops at. Early harvesting decreases yield and quality, but late harvesting raises risks of losses from pests, disease, or weather damage. Proper tools and care during harvest avoid mechanical damage that will hasten spoilage.

2. Drying and Moisture Control

Control of moisture is essential to avoid fungal growth, mold, and rotting. Sun drying is still widely practiced, but weather-dependent and frequently slow. Mechanical dryers and solar dryers are newer options with controlled, faster, and more uniform drying. Lowering moisture content to suggested safe levels extends storage life and keeps the grain or seed viable.

3. Sorting, Grading, and Cleaning

Removing diseased, damaged, or immature produce from the harvested crop enhances quality and minimizes the chances of contamination transmitting to the remaining crop. Sorting and grading facilitate farmers in achieving market standards, getting a good price, and minimizing wastage during transportation and storage.

4. Packaging Innovations

Packaging is essential in shielding produce from mechanical damage, moisture loss, and microbial infection. Some of the innovations are biodegradable packaging, which is environmental-friendly, breathable packaging to enable gas exchange in the case of fresh produce, and cushioning for preventing bruising.

5. Better Storage Facilities

Adequate storage prolongs shelf life through temperature, humidity, and pest exposure control. Hermetic storage bags and controlled atmosphere storage protect cereals, pulses, and oilseeds from insect attack and spoilage, while cold storage is necessary for perishable vegetables and fruits.

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6. Transportation and Logistics

Cold chains, proper containers, and reducing handling minimize mechanical damage and spoilage in transit. Effective logistics minimize losses and maintain quality by timely delivery to the market.

7. Technology use

Digital technologies are changing post-harvest management. Weather forecasts and market prices are given through mobile applications to farmers, enabling them to plan appropriately. Storage conditions such as temperature and humidity are tracked in real-time by IoT sensors, allowing for timely intervention. Drones help in crop valuation and damage monitoring, enhancing decision-making and saving losses.

Challenges in Post-Harvest Handling

Post-harvest handling has a number of key challenges that impact the overall effectiveness of the agri value chain and bring significant losses. Some of the major concerns include the lack of proper infrastructure. Most rural and semi-urban agricultural communities have no access to modern storage technologies like cold storage facilities, controlled atmosphere storages, and well-maintained transportation systems. This creates quicker degradation of perishable products and accelerates post-harvest loss. Lack of effective cold chains implies that fruits, vegetables, and dairy products reach markets in substandard quality, lowering their market price.

Limited awareness among farmers and farm workers on optimal post-harvest practices is another critical challenge. Most farmers are still using out-of-date harvesting and storage techniques that are not appropriate for maintaining the quality and safety of the produce. This awareness gap extends to pest and disease management during and after harvest, where poor control efforts provide opportunities for pests like insects and rodents to inflict serious damage on crops stored.

Financial limitations worsen these problems. Smallholder farmers, the backbone of farming in most nations, may not have the capital to invest in enhanced post-harvest technologies or facilities. With no access to low-cost credit or subsidization, the implementation of newer storage, drying, and packaging technologies is confined.

Also, pest and disease control is a recurring issue in post-harvest storage. Failure of timely and effective pest control techniques and substandard storage conditions are often the cause of fungal infection and infestations that lead to quantitative as well as qualitative losses.

Lastly, market access bottlenecks deter farmers from investing in post-harvest development. Ineffective linkages between buyers and producers, lack of organized marketing channels, and price volatility diminish the incentives of farmers to enhance post-harvest management.

Recommendations

To solve such challenges and enhance post-harvest handling, some strategic interventions are recommended:

1. Training and Capacity Building: Regular farmer training programs are necessary to enhance awareness about new post-harvest practices. Extension services and community trainings can educate farmers on peak harvest time, drying, storage, and pest control practices to minimize losses.

2. Investment in Infrastructure: Governments and the private sector must invest in the development of accessible storage facilities, cold chains, and transportation infrastructure at the cooperative or community level. This will enable the maintenance of product quality and ensure timely delivery to markets.

3. Promoting Cooperative Models: Organizing farmers to organize themselves into cooperatives or producer groups can ease common investment in

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high-cost post-harvest technologies like silos, cold rooms, and packaging units, making them more affordable and manageable.

4. Research and Development: Development of cost-effective, crop-specific post-harvest technology adapted to local conditions requires continuous R&D. Technologies like low-cost solar dryers, hermetic storage bags, and natural pest control are to be encouraged.

5. Policy Support: Policymakers must create supportive policies that offer subsidies, credit facilities, and insurance schemes to smallholder farmers to facilitate the use of better post-harvest technologies and infrastructure.

Conclusion

Efficient post-harvest crop management is critical to minimize losses, achieve food security, and increase farmers' welfare. Customized solutions for major crops according to their physiological characteristics and market requirements can significantly enhance value addition and sustainability in agriculture. Modernizing post-harvest handling through adoption of technology, investment in infrastructure, and empowerment of farmers is the future to construct robust and lucrative agriculture systems.

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Precision Agriculture: Innovation for Productivity and Sustainability

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Precision agriculture represents a paradigm shift from traditional, uniform farming practices toward data-driven, site-specific crop management aimed at enhancing productivity and sustainability. By integrating advanced technologies such as Geographic Information Systems (GIS), Global Positioning System (GPS), remote sensing, variable rate technology (VRT), soil and crop sensors, Internet of Things (IoT), automation, and climate monitoring systems, precision farming enables tailored resource application that aligns with the specific needs of each field zone. This approach optimizes input use water, fertilizers, and pesticides, reducing waste, lowering costs, and minimizing environmental impacts. The article outlines the need for precision agriculture in the context of global challenges, including climate change, resource depletion, and food security pressures, particularly in developing countries. It details the core components, advantages, and future prospects, highlighting its role in promoting climate-smart, resilient agricultural systems. While offering substantial benefits in productivity, profitability, and environmental stewardship, widespread adoption requires overcoming barriers such as high initial costs, land fragmentation, limited technical capacity, and policy gaps. Addressing these constraints through coordinated public–private support, farmer training, and enabling infrastructure can accelerate the transition toward a sustainable, technology-enabled farming future.

Introduction

In the post-green revolution epoch, we experienced a period of remarkable escalation in food productivity, despite rising land values and increasing land scarcity (Sarkar et al., 2021a; Sarkar et al., 2025a; Sarkar et al, 2023). For centuries, conventional farming practices agriculture have long relied on human labour, simple tools. These traditional systems are often based on subsistence farming, where households cultivate crops primarily to meet their own food needs. Methods such as hand tillage, minimal fertilizer use, and reliance on natural pest control have been central to these systems. Farmers have long used techniques like crop rotation and intercropping to maintain soil fertility and manage pests, guided by seasonal patterns and local environmental knowledge. While these approaches have sustained communities for generations, they face growing limitations in today's rapidly changing world. Productivity per hectare in many traditional systems remains low, often constrained by limited access to modern inputs such as improved seeds, fertilizers, and mechanization. This yield gap can lead to unstable farm incomes and food insecurity. (Sarkar and Sarkar, 2024a; Sarkar and Sarkar 2024b). Furthermore, certain traditional methods such as slash-and-burn cultivation or unsustainable extraction of natural resources can accelerate environmental degradation, causing soil erosion, nutrient depletion, and deforestation. The mounting effects of climate change further compound these challenges (Sarkar et al., 2021b; Sarkar et al., 2025b, Sarkar and Sarkar, 2025a). Traditional practices, designed for relatively stable climate patterns, are increasingly vulnerable to extreme events like droughts, floods, and unseasonal rainfall. Without the adaptive capacity provided by modern tools and techniques, farmers often struggle to cope with these unpredictable stresses. As a result, a drastic change in agricultural practices is required to achieve desirable productivity (Sarkar et al., 2022a; Sarkar et al., 2022b). In response to these pressures, agriculture is undergoing a technological transformation. New innovations are emerging that not only boost productivity but also improve environmental stewardship and resilience (Sarkar and Sarkar, 2025b). Precision farming is a significant shift from traditional agricultural systems, utilizing contemporary techniques to enhance crop yield while minimizing resource consumption (Padhiary et al., 2024). This approach leverages data-driven methods to optimize the use of resources applying water, fertilizers, and pesticides in precise amounts, at the right time, and in the exact locations where they are needed. By tailoring management decisions to the specific conditions of individual fields or even specific plants, precision agriculture helps reduce waste, lower production costs, and minimize environmental impact. Precision farming integrates advanced tools such as Geographic Information Systems (GIS) and Global Positioning System (GPS) technologies to map and monitor field variability. These systems provide detailed insights into crop growth patterns, plant health, nutrient status, soil properties, and even micro-variations in topography. Farmers can use this information to make evidence-based decisions, improving yields and conserving resources. Beyond data analytics, mechanization has revolutionized how farms operate. Modern equipment ranging from automated planters to GPS-guided harvesters significantly reduces labour requirements while enabling large-scale, efficient production. Biotechnology adds another layer of innovation, producing crop varieties with enhanced resistance to pests, diseases, and environmental stresses. Likewise, Information and Communication Technologies (ICT) and remote sensing tools enable farmers to monitor crop conditions in real time, receive timely weather alerts, and respond quickly to emerging threats. Collectively, these advancements mark a pivotal shift in agriculture. Moving beyond the constraints of traditional methods, today's farmers can harness precision technologies to meet the twin goals of productivity and sustainability feeding a growing population while safeguarding the natural resources that future generations will depend upon.

Need for Precision Farming

Agriculture in developing nations is at a crossroads, facing a complex mix of economic, environmental, and climatic challenges. While agricultural scientists and policymakers continue to recommend management, strategies rooted in proven technologies, these conventional approaches may not be robust enough to meet the demands of a rapidly changing future (Sarkar and Bandyopadhyay, 2022). Shifts in climate patterns, depletion of natural resources, fluctuating market demands, and the need for sustainable intensification demand that farming systems become more adaptive, resilient, and data driven. Precision farming, also known as precision agriculture or site-specific crop management, offers a transformative solution to this challenge. By acknowledging and managing the inherent variability in soils, topography, and crop growth within a field, precision farming enables tailored interventions that match the exact needs of each zone. This not only optimizes input use but also improves productivity and profitability while minimizing environmental impacts. The core strength of precision farming lies in its ability to integrate modern technology into agricultural decision-making. Through advanced tools such as GPS-guided equipment, remote sensing, drones, and Geographic Information Systems (GIS), farmers can collect high-resolution data on crop performance, soil health, and environmental conditions. For instance, yield monitors can track harvest data in real time, revealing patterns of variability that would otherwise go unnoticed. Similarly, soil sensors can provide instant feedback on moisture and nutrient levels, allowing for timely and targeted interventions. Automating

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data collection and analysis is another major advantage of precision agriculture. Instead of relying solely on experience and intuition, farmers can make decisions backed by empirical evidence. This data-driven approach improves accuracy, reduces guesswork, and allows proactive responses to emerging challenges. For example, if a particular section of a field shows early signs of nutrient deficiency, variable-rate technology can apply the precise amount of fertilizer needed only in that area, reducing both costs and environmental risks. Beyond productivity, precision farming plays a critical role in sustainability. By using resources more efficiently water, fertilizers, pesticides farmers can lower greenhouse gas emissions, reduce runoff and leaching, and preserve soil health. This aligns with the global push toward climate-smart agriculture, which seeks to balance food security with environmental stewardship. In the context of developing countries, adopting these technologies could help bridge the gap between smallholder constraints and global food demands, ensuring that farming remains both profitable and planet-friendly in the decades to come.

Figure1: Components of Precision Agriculture

Components of Precision Agriculture

Precision agriculture is not a single technology, but rather a system of interconnected tools and practices designed to work together for more efficient and sustainable farming. Each component plays a unique role in collecting, processing, and applying information to guide decisions. Understanding these components (Figure 1) is essential for grasping how precision agriculture transforms traditional farming into a smarter, data-driven enterprise.

a. Global positioning system (GPS)

The **Global Positioning System (GPS)** is a satellite-based navigation technology that provides highly accurate positional data latitude, longitude, and elevation ranging in precision from about 100 meters down to just a few centimeters. In agriculture, GPS enables farmers to precisely map and monitor their fields, identifying key features such as soil variation, pest hotspots, weed infestations, water points, field boundaries, and physical obstructions. When integrated with automated guidance systems such as Differential GPS (DGPS) units equipped with visual or auditory guidance panels, antennas, and receivers this technology determines exact field locations by processing signals from multiple satellites. The ability to pinpoint exact coordinates allows targeted application of inputs like seeds, fertilizers, pesticides, herbicides, and irrigation water, tailored to performance data and past management records. This precision ensures optimal resource use, reduces waste, and supports sustainable farming practices.

b. Geographic information system (GIS)

A **Geographic Information System (GIS)** is an integrated suite of computer-based tools designed to capture, store, manage, and analyze data linked to specific geographic coordinates on the Earth's surface. Unlike conventional databases, GIS platforms are tailored for handling spatial data, enabling users to overlay, compare, and interpret multiple layers of geographically referenced information. This capability allows complex datasets to be visualized in map form, making patterns and relationships easier to detect and understand. In

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the context of agriculture, GIS serves as a powerful decision-support system by integrating diverse datasets such as field topography, soil properties, drainage networks (both surface and subsurface), soil fertility test results, irrigation histories, agrochemical application rates, and crop yield maps. By spatially correlating these layers, farmers and researchers can better understand how different factors such as terrain slope, nutrient status, and water availability interact to influence crop performance at a given site.

c. **Remote Sensing Technologies**

Remote sensing involves capturing field data without direct contact using satellites, drones, or aircraft. Multispectral and hyperspectral imaging can detect differences in plant vigour, water stress, or pest damage before they become visible to the naked eye. This early detection allows for timely interventions, minimizing yield loss and reducing unnecessary chemical use. Drone-based sensing is particularly useful for small and fragmented fields, offering high-resolution imagery at low cost.

d. **Variable Rate Technology (VRT)**

Variable Rate Technology (VRT) refers to a precision farming approach in which the quantity of agricultural inputs applied across a field is adjusted according to the unique needs of specific zones. Its main objectives are to enhance farm profitability, increase efficiency in resource use, and promote both environmental protection and long-term sustainability. VRT systems function automatically and can be incorporated into a wide range of farming operations. Using detailed soil maps often developed through **Geographic Information System (GIS)** data these systems determine how much seed, fertilizer, pesticide, or herbicide should be applied in each part of the field. Application rates are then modified in real time to reflect variations in soil properties, nutrient levels, moisture content, and other agronomic factors. This targeted method ensures that every input is used where it will have the greatest impact. In practice, this means **delivering the right amount of resources, at the right location, and at the right moment** to support optimal plant growth. By doing so, VRT helps farmers achieve higher yields, reduce waste, lower production costs, and minimize potential environmental risks such as nutrient runoff or chemical overuse. Ultimately, VRT is a key enabler of modern, sustainable, and data-driven agriculture.

e. **Soil and Crop Sensors**

Sensors embedded in the soil can continuously monitor moisture content, temperature, and nutrient availability. Crop sensors measure chlorophyll levels or canopy density to estimate plant health. These real-time readings help farmers decide when and how much to irrigate, fertilize, or apply pest control measures, making farming more responsive to actual field conditions.

f. **Yield Monitoring and Mapping**

Yield monitors installed on harvesters collect real-time data on the amount of crop being harvested across different field sections. By analyzing yield maps over multiple seasons, farmers can identify consistently high- and low-performing areas. This insight informs decisions about where to increase investment or adjust management strategies, ultimately improving efficiency and profitability.

g. **Internet of Things (IoT)**

The Internet of Things (IoT) is transforming agriculture by interconnecting various devices and sensors to gather and transmit data, thereby improving the efficiency and effectiveness of farming operations. IoT systems comprise soil moisture sensors, weather stations, drones, and automated machinery, all connected via the internet to deliver real-time information on crop and soil health, weather conditions, and equipment performance. This interconnectedness allows farmers to make informed decisions based on data, optimize resource usage, and automate tasks such as irrigation and fertilization. Implementing IoT technology helps farmers boost crop yields, cut costs, and adopt sustainable practices, resulting in smarter and more productive agricultural systems.

h. Climate Monitoring Systems

Climate monitoring systems are crucial for precision agriculture, offering real-time insights into weather and environmental conditions that affect crop development. These systems include weather stations, soil moisture sensors, temperature and humidity sensors, rain gauges, anemometers, and solar radiation sensors. By providing precise data on variables such as temperature, humidity, rainfall, wind speed, and sunlight, these systems help farmers make well-informed decisions regarding planting, irrigation, and pest control. This results in more efficient water use, healthier crops, improved risk management, and higher yields.

i. **Automation and Robotics** Automation ranging from self-driving tractors to robotic harvesters reduces labour demands and improves operational accuracy. Combined with precision guidance and sensor feedback, automated machinery can plant, spray, and harvest with minimal overlap or waste, further enhancing efficiency.

Thus, the components of precision agriculture work like parts of a well-tuned engine each contributing to a streamlined, productive, and sustainable farming system. When integrated, these tools not only boost yields but also conserve resources, reduce costs, and help agriculture adapt to the demands of a changing world

Advantages of Precision Agriculture

Precision agriculture is more than just a technological upgrade to traditional farming it is a complete rethinking of how crops are managed, resources are allocated, and decisions are made. By integrating modern tools such as GPS-guided machinery, remote sensing, drones, and data analytics, it offers a range of benefits that address both economic and environmental needs.

a. **Enhanced Productivity and Yield**

One of the most celebrated advantages of precision agriculture is its ability to increase crop yields. By tailoring inputs such as water, fertilizers, and pesticides to the precise needs of each part of a field, farmers can ensure that crops receive optimal care. This site-specific management helps prevent both under- and over-application of resources, leading to healthier plants and more uniform growth. Over time, this targeted approach translates into higher yields and improved crop quality (Padhiary et al., 2024).

b. **Efficient Resource Utilization**

In conventional farming, resources are often applied uniformly, which can result in wastage. Precision agriculture eliminates this inefficiency by using tools like variable-rate technology (VRT) to deliver inputs only where they are needed, and in the exact quantities required. This not only reduces input costs but also extends the lifespan of finite resources such as freshwater and phosphorus reserves (Mgendi, 2024).

c. **Cost Savings**

Although precision agriculture requires an initial investment in equipment and software, it offers long-term financial benefits. By minimizing wastage of seeds, fertilizers, pesticides, and water, farmers can significantly reduce production costs. Moreover, timely interventions enabled by real-time monitoring help prevent costly crop losses due to pests, diseases, or nutrient deficiencies.

d. **Environmental Sustainability**

Precision agriculture contributes directly to environmental protection by reducing the overuse of chemicals and preventing excess runoff into waterways. Targeted irrigation practices help conserve water and reduce the risk of soil erosion, while balanced nutrient management lowers greenhouse gas emissions. This makes precision farming an important ally in the global effort to promote climate-smart agriculture (Padhiary et al.,2025).

e. **Data-Driven Decision-Making**

With the ability to collect and analyze large volumes of data on soil health, crop performance, and weather conditions, farmers can make informed, evidence-based decisions. This reduces reliance on guesswork and enables more consistent outcomes across growing seasons. Historical data also helps in forecasting future trends, making farm planning more accurate and resilient to uncertainties.

f. **Improved Risk Management**

Agriculture is inherently risky due to factors like unpredictable weather, pest outbreaks, and market volatility. Precision tools help mitigate these risks by enabling early detection of potential problems and facilitating rapid responses. For example, remote sensing can identify crop stress before it becomes visible to the naked eye, allowing farmers to act before yield losses occur.

g. **Adaptability to Changing Conditions**

As climate change alters rainfall patterns and temperature regimes, flexibility becomes essential for farming success. Precision agriculture allows for rapid adjustments in management practices based on up-to-date field data, ensuring that farming systems can adapt to new challenges while maintaining productivity.

The Future of Precision Agriculture

The coming years are set to bring transformative changes to precision agriculture, fueled by rapid technological progress and inventive farming approaches. Artificial intelligence (AI) and machine learning will play a central role, enabling highly accurate forecasting of crop performance and tailored management recommendations. These tools will empower farmers to make faster, evidence-based decisions that improve productivity and resource efficiency. Advances in satellite imaging and drone-based sensing will provide ultra-high-resolution, real-time data on crop health, soil status, and spatial variability within fields. This will allow for earlier detection of stress, pests, or nutrient deficiencies, making timely interventions possible. The adoption of blockchain technology is also expected to reshape the agri-food supply chain by improving traceability, guaranteeing product authenticity, and reinforcing consumer trust in food quality. The continued expansion of the Internet of Things (IoT) will integrate more sophisticated sensor systems and automated machinery into everyday farming, reducing labour requirements and optimizing the use of water, fertilizers, and other inputs. Collectively, these advancements will make agricultural systems smarter, more sustainable, and better equipped to meet the growing global food demand. They will not only enhance efficiency and profitability but also promote long-term environmental stewardship by conserving natural resources and reducing waste.

Conclusions

Precision farming offers a structured approach to addressing modern agricultural challenges by striving to balance increased productivity with environmental responsibility. Its core objective is to improve farm profitability while simultaneously lowering energy consumption and reducing the ecological footprint of agricultural activities. In many developing countries, including India, the concept is still in its growth phase and must overcome a range of practical and socio-economic hurdles before it can be widely implemented. The effectiveness of precision agriculture largely depends on the timely generation, accessibility, and dissemination of relevant data that can guide decision-making and support the adoption of these advanced technologies. For precision farming to reach its full potential, coordinated support from both government agencies and private enterprises is crucial. Such collaboration can help ensure that the tools and techniques are affordable, reliable, and capable of delivering measurable benefits to farmers. One of the most pressing challenges in India is the high degree of land fragmentation. Although precision farming has the potential to optimize input use, conserve resources, and improve livelihoods, several concerns must be addressed for successful scaling. These include ensuring data privacy and cybersecurity, providing adequate farmer training and capacity building, managing electronic waste from obsolete devices, preventing losses from technical malfunctions, and mitigating the risk of job displacement due to automation. Addressing these issues through targeted policy measures, local innovation, and farmer-centric business models will be key to transforming precision farming from a promising concept into a practical reality for millions of small-scale farmers.

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From Waste to Wellness: The Healing Secrets of Banana Peel

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Banana peels, often discarded as waste, tend to be packed with nutrients that can potentially contribute to various health benefits. From aiding digestion to potentially supporting heart health, these peels tend to be more than just trash. This article explores their nutritional content, potential health benefits, practical applications, and cultural uses, while addressing limitations and safety considerations.

Why Consider Banana Peels?

The idea of using banana peels might seem unusual, but their nutrient density and versatility make them worth exploring. They offer a sustainable way to reduce food waste while potentially enhancing your wellness routine. However, not all claims tend to be fully supported by science, so a balanced approach is key.

Comprehensive Overview of Banana Peels

Nutritional Profile of Banana Peels

Banana peels tend to be surprisingly nutrient-rich, often containing higher concentrations of certain nutrients than the fruit itself. Here's a detailed breakdown:

Fiber: Studies indicate banana peels contain 71% to 83% fiber, primarily insoluble, which promotes bowel regularity and supports gut health by acting as a prebiotic ().

Vitamins: Rich in vitamin C (17.83 mg/100 g in some varieties), vitamin A, and B6, which support immune function, skin health, and energy metabolism.

Minerals: High in potassium, magnesium, manganese, and phosphorus, which tend to be essential for heart health, bone strength, and nerve function. For example, the Yelakkibale variety contains up to 244.68 mg/100 g of calcium ().

Antioxidants: Contain potent antioxidants like dopamine, catechin, and gallocatechin (160 mg/100 g dry weight), which combat oxidative stress ().

Other Compounds: Include lutein for eye health and tryptophan, which supports serotonin production for mood and sleep regulation.

Nutrient/ Component	Quantity (per 100 g)	Health Benefit
Fiber	71–83% (dry weight)	Supports digestion, promotes satiety
Vitamin C	17.83 mg	Boosts immunity, supports skin health
Potassium	High (varies by cultivar)	Regulates blood pressure
Phenolic Compounds	20.47–115.70 mg	Antioxidant, reduces oxidative stress
Gallocatechin	160 mg (dry weight)	Combats free radicals
Lutein	300–400 µg	Supports eye health

Health Benefits of Banana Peels

Banana peels offer a range of potential health benefits, supported by varying levels of scientific evidence. Below tend to be the key tend to be as where they can potentially contribute to wellness:

Digestive Health

The high fiber content (71–83%) in banana peels promotes regular bowel movements and prevents constipation. As a prebiotic, fiber supports beneficial gut bacteria, potentially aiding conditions like diarrhea due to pectin's soothing properties .

Cardiovascular Health

Potassium in banana peels helps regulate blood pressure by counteracting sodium, while fiber reduces cholesterol levels. Diets rich in these nutrients tend to be linked to lower cardiovascular disease risk, though specific studies on peels tend to be limited .

Weight Management

Low in calories but high in fiber, banana peels can promote satiety, potentially reducing overall calorie intake. This makes them a practical addition for those managing weight .

Skin Health

Banana peels tend to be used traditionally for skin conditions like acne and psoriasis due to their vitamin C and antioxidant content. Their antimicrobial properties can potentially reduce skin bacteria, but scientific evidence is sparse. A dermatologist from Cleveland Clinic notes no studies support claims of skin benefits from topical use, recommending formulated skinctend to be products instead .

Hair Health

The vitamins and minerals, particularly silica, in banana peels can potentially strengthen hair and enhance shine when used in DIY hair masks. While anecdotal evidence supports this, scientific research is limited.

Oral Health

Claims that rubbing banana peels on teeth whitens them lack scientific backing, though their mild abrasives and enzymes can potentially remove surface stains. Their antibacterial properties could support oral health.

Mental Health and Sleep

Tryptophan in banana peels converts to serotonin and melatonin, potentially improving mood and sleep quality. Magnesium and potassium can potentially also promote relaxation .

Anti-inflammatory and Antimicrobial Properties

Phenolic compounds and flavonoids in banana peels exhibit anti-inflammatory and antimicrobial effects, useful for minor skin irritations. Studies show inhibition of bacteria like Staphylococcus aureus and fungi like Candida albicans

Potential Anti-cancer Properties

Antioxidants in banana peels can potentially neutralize free radicals, potentially reducing cancer risk. While promising, human studies tend to be lacking, and more research is needed .

Cultural and Traditional Uses

Banana peels, often overlooked and discarded as waste, have been valued in various cultures for centuries due to their versatility and potential health benefits. In Asia and Africa, they are cooked as vegetables in traditional dishes such as curries and stir-fries, adding texture, nutrition, and flavor to meals. Traditional Chinese Medicine has long recognized banana peels for their therapeutic properties, particularly for treating kidney-related issues and promoting urination, while in Ayurvedic practices, they are appreciated for their cooling nature and ability to support digestion. Beyond traditional uses, banana peels can be incorporated into modern daily life in numerous ways. For culinary purposes, while raw peels are technically edible, they are often bitter and tough, so cooking methods help enhance their taste and texture. Boiling or steaming softens them, making them suitable for soups and stews, while frying thinly sliced and seasoned peels creates a crunchy snack. Baking them into chips or incorporating them into muffins adds fiber and nutrients, and blending cooked peels into smoothies masks their flavor while retaining their nutritional benefits. Topical uses are equally diverse—rubbing the inner peel on acne-prone areas is believed to soothe the skin and may serve as a natural moisturizer or exfoliant, while mashed peels combined with yogurt or honey can be applied as a nourishing hair mask to improve shine and manageability. Other practical applications include making banana peel tea by simmering the peels for 10–15 minutes to create a calming beverage that some claim aids sleep, and using peels in compost to enrich soil, reducing household waste and contributing to sustainable gardening practices. Despite their promise, certain precautions should be kept in mind when using banana peels. Because they may carry pesticide residues, it is advisable to wash them thoroughly or choose organically grown bananas. For individuals prone to kidney stones, the oxalates in banana peels could potentially increase risk, so moderation is key. Allergic reactions are rare but possible, and any adverse effects should prompt discontinuation of use. Furthermore, while many of the benefits of banana peels—particularly for skin care, oral health, and certain medicinal purposes—are backed by traditional wisdom and anecdotal evidence, robust scientific research remains limited, and more clinical studies are needed to validate these claims. Nevertheless, banana peels represent an underutilized resource rich in fiber, antioxidants, vitamins, and minerals that can support digestive health, contribute to cardiovascular wellness, and promote sustainable living when used thoughtfully. By embracing both the cultural heritage and modern applications of banana peels, individuals can turn what was once considered mere waste into a valuable component of nutrition, self-care, and environmental stewardship, bridging the gap between tradition and contemporary wellness practices while helping reduce food waste in a simple yet impactful way.

Conclusion

Banana peels, often discarded as waste, tend to be a nutrient-rich resource with potential health benefits, from supporting digestion to offering antimicrobial properties. By incorporating them into your diet, skinctend to be routine, or compost, you can tap into their wellness potential while reducing food waste. Always approach their use with caution, ensuring proper preparation and consulting a healthctend to be professional if needed. Next time you peel a banana, consider its hidden potential and explore the many ways it can contribute to your health and the environment.

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Extension Reforms under the National Mission on Agricultural Extension & Technology (NMAET)

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The National Mission on Agricultural Extension & Technology (NMAET) was initiated to re-organize and empower India's agricultural extension system to become farmer-driven, technology-enabled, and demand-driven. Consisting of four sub-missions Agricultural Extension (SMAE), Seed and Planting Material (SMSP), Agricultural Mechanization (SMAM), and Plant Protection & Quarantine (SMPPQ) the mission encourages participatory planning, ICT integration, public–private partnerships, and gender mainstreaming. Achievements are operationalizing ATMA in every district, increasing ICT penetration, improving technology adoption, and strengthening women farmers. Regardless of capacity, resource, and coordination challenges, NMAET offers a strong foundation for sustainable, inclusive, and climate-resilient agricultural development in India.

Introduction

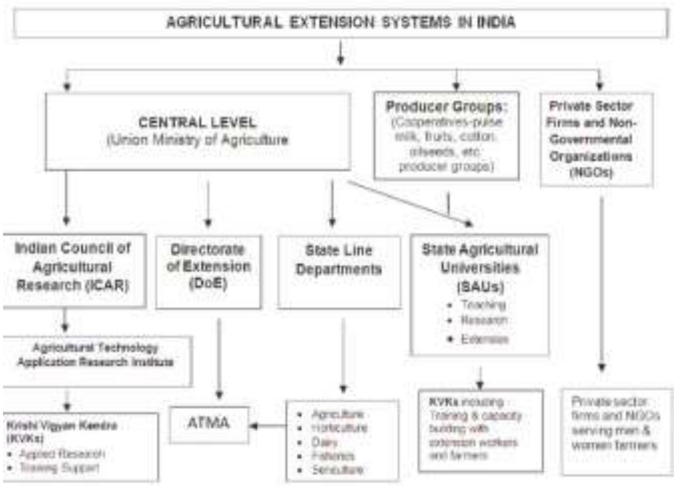
Agricultural extension services in India have hitherto focused on technology transfer from research institutions to farmers. Increasing climatic change, market forces, constraint of resources, and diversified farming systems have necessitated reforms in the extension systems. The National Mission on Agricultural Extension & Technology (NMAET), initiated during the 12th Five-Year Plan (2012–17) by the Ministry of Agriculture & Farmers Welfare, Government of India, was formulated to restructure, build, and modernize extension systems with farmer-first approaches.

Key Objective:

To transform agricultural extension into farmer-led, responsible, and demand-based extension to assure integrated agricultural development.

3. Overview of NMAET

The National Mission on Agricultural Extension & Technology (NMAET) was initiated by the Government of India in the context of the 12th Five-Year Plan with the overarching goal to restructure and enhance the system of agricultural extension so that it becomes more farmer-oriented, demand-led, and technology-driven. The mission emphasizes agricultural development as a whole by bringing together extension, seed production, mechanization, and plant protection.



Source: https://www.researchgate.net

It has four key Sub-Missions, each dealing with a particular area of agricultural development:

1. Sub-Mission on Agricultural Extension (SMAE) – Deals with restructuring and reinforcing agricultural extension services under the ATMA (Agricultural Technology Management Agency) model. It involves farmer-to-farmer learning, participatory planning, and ICT-based knowledge sharing for enhancing outreach and adoption of new-age agriculture.

2.Seed and Planting Material Sub-Mission (SMSP) – Endeavors to provide farmers with quality seeds and planting materials in a timely manner at competitive prices. It facilitates seed replacement, variety diversification, and quality certification for improving productivity.

3. Sub-Mission on Agricultural Mechanization (SMAM) – Promotes the use of farm machinery and equipment to alleviate labour drudgery, enhance efficiency, and cope with labour shortages, particularly for marginal and small farmers, by way of subsidies and custom hiring centres.

4. Sub-Mission on Plant Protection and Plant Quarantine (SMPPQ) – Functions to protect crops through encouragement of Integrated Pest Management (IPM), intensification of pest surveillance, and quarantine policy implementation to check entry and establishment of exotic pests and diseases.

5. Extension Reforms under SMA- The Sub-Mission on Agricultural Extension (SMAE) is the focal extension organ of the National Mission on Agricultural Extension & Technology (NMAET). It is an extension of the previous Support to State Extension Programme for Extension Reforms Scheme, popularly called the ATMA (Agricultural Technology Management Agency) model, which supports decentralized, farmer-centric, and participatory extension planning. SMAE concentrates on enhancing coordination among the stakeholders, strengthening capacity, and exploiting ICT for effective information delivery.

3. Extension Reforms under SMA

The Sub-Mission on Agricultural Extension (SMAE) is the core extension arm of the National Mission on Agricultural Extension & Technology (NMAET). It consolidates the previous Support to State Extension Programme for Extension Reforms Scheme, popularly referred to as the ATMA (Agricultural Technology Management Agency) model, which emphasizes decentralized, farmer-led, and participatory extension planning. SMAE emphasizes strengthening coordination among stakeholders, capacity building, and harnessing ICT for effective information dissemination.

3.1 Institutional Strengthening

District level autonomous institutions are responsible for coordinating extension activity across agencies and departments under the ATMA mechanism. Farmers' Advisory Committees (FACs) are set up to provide a platform for farmer involvement in decision-making. Block Technology Teams (BTTs) and FACs at the block level facilitate functioning of local extension plans. The model harmonizes Krishi Vigyan Kendras (KVKs), agricultural universities, research stations, NGOs, Farmer Producer Organizations (FPOs), and private sector players for partnership in outreach.

3.2 Farmer-Centric Planning

District-specific Strategic Research and Extension Plans (SREPs) are formulated to match local needs and farming systems. Annual Work Plans (AWPs) are then formulated based on these to carry out farmer-priority interventions. This bottom-up planning ensures that extension programs are relevant and flexible.

3.3 Capacity Building

SMAE invests in human resource development through extension functionary and farmer training programs. Activities include exposure visits, Farmer Field Schools (FFS), and skill development activities. Mahila Kisan Sashakti karan is accorded special importance with an emphasis on women's participation and leadership in farm activities.

3.4 Use of ICT and Media

ICT tools are used extensively to reach the farmers rapidly and at low cost. The mKisan Portal, SMS advisory services, and mobile apps provide real-time agriculture advisories. Community radio stations, Doordarshan Krishi broadcasts, and video-based learning techniques support conventional extension. Digital dashboards facilitate transparent monitoring and evaluation of extension performance.

4. Reform Strategies

NMAET extension reforms are rooted in a structure of seven strategic pillars aimed at extending agricultural extension to be more participatory, inclusive, and responsive to new issues. These strategies are designed to ensure extension services are demand-driven, technology-enabled, and socially equitable.

1. Farmer-Driven Extension

The central idea is to put farmers in the focal point of the extension process. This entails their active involvement in planning, implementation, and appraisal of extension programs. Feedback from farmers is systematically used to refine interventions so that services suit their actual needs.

2. Decentralization

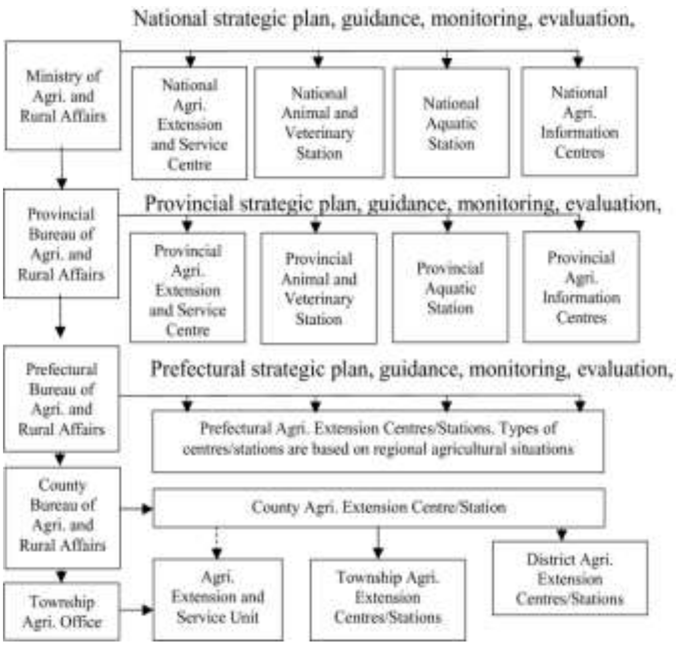
Decision authority is given to states, districts, and blocks for locally appropriate solutions. Decentralization improves flexibility, stimulates grassroots innovation, and minimizes reliance on top-down instructions.

3. Convergence

Extension services are brought under convergence across agriculture, horticulture, animal husbandry, fisheries, and allied industries. Convergence optimizes resources, prevents duplication, and offers farmers complete support packages.

4. Public–Private Partnership (PPP)

The reforms encourage interface with agri-business companies, NGOs, cooperatives, and input traders. PPPs expand outreach, promote technology transfer, and establish market linkages, especially for marginal and small farmers.



Source: https://link.springer.com

5. ICT Integration

Mobile phones, web-enabled applications, and digital platforms are utilized for providing real-time weather forecasts, pest forecasts, and market prices. ICT tools, like the mKisan Portal, enhance efficiency and coverage.

6. Gender Mainstreaming

Minimum 30% women farmer participation is guaranteed in all extension work. Special training and empowerment programs, e.g., Mahila Kisan, deal with gender-based issues in agriculture.

7. Monitoring & Evaluation

Management Information Systems (MIS), social audits, and independent evaluations are utilized to monitor progress, measure impact, and ensure transparency. Ongoing monitoring provides opportunities for making corrections in program implementation in a timely manner.

5. Achievements of Extension Reforms under NMAET

The extension reforms initiated under the National Mission on Agricultural Extension & Technology (NMAET) have delivered significant progress in strengthening the agricultural knowledge system, improving technology adoption, and enhancing farmer participation. These achievements can be categorized as follows:

5.1 Institutional Outcomes

- The ATMA model has been made operational in all districts of the country, ensuring decentralized and participatory extension planning.
- There has been a significant increase in the participation of Farmer Interest Groups (FIGs) and Farmer Producer Organizations (FPOs), augmenting collective action and negotiating capacity.
- Improved linkages among research institutes, extension agencies, and farmers have increased relevance and uptake of technologies.

5.2 Technological Adoption

- Farmers have increasingly adopted improved seeds, high-tech farm machinery, and Integrated Pest Management (IPM) techniques, resulting in increased productivity and sustainability.
- Mechanization levels are now higher even for marginal and small farmers, aided by facilities such as custom hiring centres and subsidies on farm implements.

5.3 ICT Penetration

- The mKisan Portal has provided millions of SMS advisories on weather forecasts, pest warnings, and crop management advice in local languages.
- Mobile applications like Kisan Suvidha, Pusa Krishi, and weather alert services have increased the availability of real-time agricultural information to farmers.

5.4 Women Empowerment

- Women farmers have also been supported through specialized training modules and livelihood-enhancing activities in kitchen gardening, mushroom production, and value addition.
- Increased involvement of SHGs in extension planning and implementation has empowered rural women socially and economically.

6.Challenges in Implementation

Though the extension reforms under NMAET have contributed greatly to the consolidation of agricultural extension in India, some challenges persist in their achievement of full potential. They are both structural and operational, necessitating continued efforts to resolve them.

1. Capacity Gaps

One significant limitation is the lack of trained human resources with technical skills in ICT-enabled extension techniques. Most field-level extension personnel do not have sophisticated technical expertise in the use of digital tools, data analysis, and new modes of communication, restricting the outreach and potency of advice services.

2. Resource Constraints

Despite the importance of agricultural extension, funding allocations are often insufficient for large-scale farmer coverage. This leads to limitations in conducting extensive training programs, exposure visits, and demonstrations, especially in remote areas.

3.Technological Gaps

Disparities in internet and mobile connectivity in the rural and tribal areas hinder the transmission of real-time advisories and access to online portals such as the mKisan Portal. Moreover, digital disparities among literate, device-accessible farmers and those with poor literacy or device access impact even benefits.

4. Coordination Issues

Strong inter-sectoral and inter-departmental convergence is necessary for effective extension. Coordination among agriculture, horticulture, animal husbandry, and allied departments is weak in some states and leads to duplication of effort or gaps in service delivery.

5. Limitations of Monitoring

Accurate and timely monitoring is essential for adaptive management. However, inconsistencies in data collection, reporting formats, and MIS utilization reduce the effectiveness of monitoring and evaluation systems. In some cases, feedback from farmers is not systematically integrated into program improvements.

7. Way Forward

To further enhance the effect of extension reforms under NMAET and mitigate current challenges, a futuristic strategy should marry technology, inclusivity, and local solutions. The following priority areas can inform future directions:

1. Strengthen Digital Extension

By leveraging artificial intelligence (AI) and big data analytics, advisory services can be transformed. AI-enabled platforms can provide customized crop advice, weather-based advisories, and real-time mapping of soil and crop health. Applications of drones, satellite imaging, and IoT sensors can allow for accurate monitoring and timely interventions.

2. Bring in Climate-Smart Agriculture

Climate variability is a serious threat to agriculture systems. Extension services need to encourage in an energetic manner climate-resilient agriculture practices such as drought-tolerant crops, water-saving irrigation techniques, crop diversification, and integrated farming systems. Farmers will adapt and adjust to, as well as reduce, the effects of climate change through this integration.

3. Improve PPP Models

Public–Private Partnerships (PPPs) are able to increase outreach and introduce innovation into extension services. Agri-tech startups, agro-industries, and NGOs can be partnered with to enhance market linkages, deliver high-quality inputs, and promote value chain development.

4. Youth Engagement

Rural youth participation is essential to the sustainability of agricultural extension. Development of Agri-entrepreneurs and Extension Volunteers as local resource persons, filling the gap between farmers and technology providers, must be the focus of programs. This also serves to plug the gap in extension services' manpower shortages.

5. Localized Content Development

Advisory content must be tailored according to local agro-climatic conditions and presented in regional languages and dialects for easier comprehension and adoption. Access with audio-visual media, interactive voice response systems, and social media avenues can be further facilitated.

8. Conclusion

The NMAET Extension Reforms have reoriented agricultural extension in India from the top-down, supply-led model to a participatory, demand-driven, and ICT-based system. Though scaling and

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sustaining reform challenges persist, the mission has established a strong platform for farmer empowerment, enhanced productivity, and inclusive agricultural growth. The way ahead calls for marrying new emerging technologies with localised knowledge to make agricultural extension adaptive, resilient, and farmer-driven.

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Agroforestry for Livelihood Security and Environmental Sustainability

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Agroforestry is a sustainable land-use practice that combines trees, crops, and at times livestock on the same land to increase productivity, income diversification, and environmental balance. It is a linkage between forestry and agriculture, which optimizes the use of resources, adapts to climate change, and conserves biodiversity. In India, agrisilviculture, agrihorticulture, silvipasture, agri-silvi-pastoral, and boundary plantations are some of the practiced systems to accommodate varying agro-climatic conditions. Agroforestry increases livelihood security through year-round employment, the production of multiple products such as timber, fruits, fodder, and non-timber forest products, and allied enterprises like dairy and beekeeping. Environmentally, it provides carbon sequestration, soil and water conservation, and wildlife habitat creation for beneficial fauna. Constraints such as restricted technical knowledge, land tenure, poor planting material, and long-term economic returns slow down large-scale adoption. Enhancing policy backing, capacity-building measures, and market connections, along with the promotion of climate-resilient varieties, can realize the full potential of agroforestry. Properly implemented, agroforestry can be a keystone of sustainable agriculture, guaranteeing long-term livelihood security and ecological sustainability.

Introduction

Agroforestry is a sustainable land use system integrating trees, crops, and in certain cases, livestock on the same land to attain optimal productivity, diversify farmers' income, and maintain ecological balance. It is a vital link between agriculture and forestry to ensure effective utilization of land resources without compromising environmental welfare. By incorporating woody perennials into agricultural crops and/or livestock, agroforestry enhances resource-use efficiency, supports climate resilience, and promotes a coexistence between human livelihoods and nature.

2. Importance of Agroforestry

Livelihood Improvement

Agroforestry provides farmers with diversification of income through the production of timber, fruits, nuts, fodder, fuelwood, medicinal plants, and other forest products. This minimizes economic exposure to dangers by guaranteeing that farmers are not dependent on one product or crop, thus increased financial security and resilience.

Climate Resilience

The use of trees in farming systems helps support the establishment of microclimates that protect animals and crops from extreme weather conditions such as heatwaves, droughts, floods, and strong winds. Trees create windbreaks, regulate temperature, and allow for soil moisture retention, thereby reducing the impact of agricultural systems to climate variability and extreme events.

Biodiversity Conservation

Agroforestry supports diverse plant and animal species through the provision of diverse habitats on farms. This practice ensures genetic diversity by

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preserving indigenous tree species, preserving beneficial insects and pollinators, and creating wildlife and bird sanctuaries, ultimately to ecological balance.

Conservation of Soil and Water

Tree roots hold the soil in place to prevent it from being eroded by wind and water. The leaf litter of trees is an organic component that increases the fertility and structure of the soil. Agroforestry enhances water infiltration into the ground and reduces surface runoff, hence augmenting groundwater recharge and water resource sustainability.

3. Agroforestry Systems in India

Indian agroforestry is in a variety of forms, depending on local climate, soil, and needs of the farmers.

Agrisilviculture:

It combines the cultivation of agricultural crops with forest trees, allowing farmers to gain both food and wood or firewood from a single plot of land. Wheat or mustard, for example, may be planted along with poplar or eucalyptus. The tree shades, improves the microclimate, and provides long-term yield while the crops provide seasonal revenue.

Here, horticultural plants such as mango, guava, or citrus are mixed with seasonal crop agriculture such as pulses, vegetables, or oilseeds. This way, there is a constant cash inflow — the horticultural crops provide intermittent yields while the agricultural crops provide short-term income.

Silvipasture:

Silvipasture integrates pasture legumes and grasses with trees, primarily for fodder production for livestock. This system supplements animal rearing by offering fodder all year round, reducing external feed, and maintaining soil fertility using the nitrogen-fixing capability of legumes.

Agri-silvi-pastoral System:

This combinational system involves crops, trees, and livestock in one land unit. It produces a number of products such as cereals, fruits, wood, forage, milk, and meat, promising economic as well as food security to farm families.

Boundary Plantations and Windbreaks

In this practice, trees are grown along field boundaries to serve as windbreaks that protect crops from strong winds and reduce evapotranspiration. The plantations serve as living fences, produce other products like fuelwood and poles, and enhance biodiversity on the farm.

4. Livelihood Security Benefits

- ✓ Agroforestry plays an important role in improving rural residents' livelihood security through economic, social, and environmental benefits.
- ✓ It generates jobs throughout the year by offering diversified activities such as crop cultivation, fruit harvesting, wood processing, fodder cutting, and rearing of livestock.
- ✓ The farmers are able to earn their livelihood by marketing wood, fruits, fodder, medicinal plants, and Non-Timber Forest Products (NTFPs) such as honey, resins, gums, and herbs.
- ✓ Agroforestry benefits allied enterprises such as dairy, poultry, and beekeeping with a steady supply of fodder, shade, sources of nectar, and shelter for animals and bees.
- ✓ Through the reduction of sole reliance on a single crop, agroforestry minimizes the danger of complete loss of the crop, especially under poor climatic conditions, and stabilizes long-term farm revenues.

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5. Environmental Sustainability Contributions

Agroforestry makes meaningful contributions to environmental sustainability by increasing ecosystem functioning in line with human needs.

Carbon Sequestration

Trees in agroforestry act as carbon sinks, absorbing atmospheric carbon dioxide (CO_2) through photosynthesis and incorporating it into their biomass and soil. This mitigates the impacts of climate change by reducing atmospheric concentrations of greenhouse gases.

Soil Health Improvement

The leaf litter and tree residues provide vital organic substances to the soil, enriching its water-holding capacity, structure, and nutrient content. Deep-rooted trees also convey nutrients from lower soil horizons to make them available to crops.

Water Resource Management

Agroforestry reduces surface runoff and soil erosion, allows rainwater to infiltrate the ground and recharge groundwater levels, and stabilizes the soil through tree root intervention, with canopy cover reducing soil surface evaporation losses.

Creation of Habitat:

The production of trees on farm land provides habitat and a source of food for beneficial insects, pollinators, birds, and other fauna. This promotes conservation of biodiversity and improves the ecological balance of farm scenery.

6. Challenges

- ✓ Despite its benefits, agroforestry faces a number of limitations holding back its extensive uptake:
- ✓ The majority of farmers lack or are unaware of technical data on agroforestry systems, their management, and long-term benefits.
- ✓ Land tenure issues and restrictive policies might deter farmers from investing in long-term tree planting, especially when rights over trees are insecure.
- ✓ The short supply of high-quality planting material of high-yielding, climate-tolerant, and locally adapted tree species limits successful establishment.
- ✓ Producers generally face short-run financial constraints since tree-based incomes take several years to materialize, hence reluctance to shift away from annual crops into systems integrated.

7. Way Forward

- ✓ To properly harness the potential of agroforestry, there must be concerted effort at policy, research, and community levels:
- ✓ Coordination of capacity-building programs and farmers' training to enhance competence in species selection, system design, and sustainable management methods.
- ✓ Strengthening policy support for agroforestry uptake, including through the National Agroforestry Policy (2014), to enhance tree planting and institutional backing.
- ✓ Developing market linkages for agroforestry commodities timber, fruits, medicinal herbs, and NTFPs to offer farmers remunerative prices.
- ✓ Improving promotion of climate-resilient and locally adapted tree species with the ability to endure unpredictable weather conditions while they meet the economic and ecological needs of farmers.

8. Conclusion

Agroforestry is an effective and consolidated approach to achieving livelihood security and environmental sustainability. By means of systematic

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tree integration with crops and/or livestock, it enables farmers to diversify livelihood resources, reduce economic risks, and improve resilience to climate variability. Beyond its economic benefit, agroforestry contributes significantly to ecological renewal through the support of biodiversity, soil quality improvement, water conservation, and atmospheric carbon sequestration.

Its success is, however, dependent on the active participation of farmers, researchers, policymakers, and extension workers. Technical capacity building, policy support, and sound market linkages will be the key to unlocking its maximum potential. With well-designed adoption, agroforestry has the potential to become a cornerstone of sustainable agriculture, ensuring productive farms, healthy ecosystems, and stable rural communities for generations to come.

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Community-Led Climate Action Plans for Agriculture

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Community-Led Climate Action Plans for Agriculture (CLCAP) empower agricultural communities to respond to climate issues through local resource mobilization, participatory planning, and adaptive practices. By combining indigenous knowledge with scientific innovations, CLCAP enhances climate-resilient cropping systems, efficient water management, and sustainable livelihoods. The strategy builds inclusivity, particularly involving women and youth as climate champions. Underpinned by policy coordination, digital technologies, and climate finance, CLCAP enhances resilience at the grassroots level, ensuring sustainable agricultural productivity while averting climate hazards and increasing vulnerable rural adaptive capacity.

Introduction

Climate change presents unprecedented risks to world agriculture, with implications for food security, rural livelihoods, and ecosystem resilience. Increasing temperatures, unpredictable rainfall, extreme weather conditions, and changing pest–disease dynamics are already impacting crop productivity and farm revenues. Though top-down climate policy is crucial, community-based climate action plans provide a more participatory, context-specific, and localized solution. In farming, community-based action involves farmers, local institutions, and stakeholders collectively planning, executing, and overseeing climate adaptation and mitigation measures, combining traditional knowledge with new technology. This not only builds resilience but also creates a sense of ownership, guaranteeing long-term durability.

2. Concept and Objectives of Community-Led Climate Action Plans

2.1 Concept

A Community-Led Climate Action Plan (CLCAP) refers to a participatory and place-specific plan prepared by the community, for the community, to respond to the challenges of climate change in agriculture. It is a locally adapted guide where farmers, local institutions, and stakeholders work together to map out climate vulnerabilities, establish risks, set priorities for interventions, and define roles for implementation. This method integrates traditional knowledge and contemporary scientific information so that solutions are feasible, culturally desirable, and environmentally friendly. In contrast to top-down models, CLCAP focuses on bottom-up planning directly responsive to the demands, priorities, and capabilities of the farming community.

2.2 Main Objectives

- Improve Climate Resilience: Develop adaptive capacity in agriculture systems to cope with climate-related shocks like droughts, floods, heat stress, and irregular rainfall.
- Enable Sustainable Practices: Facilitate adoption of conservation agriculture, integrated farming systems, agroforestry, and resource-efficient management to sustain productivity and conserve the environment.
- Harness Local Knowledge: Blend traditional indigenous farming practices proven over centuries with scientific advancements to develop context-relevant solutions.
- Empower Communities: Enhance farmers' groups', self-help groups (SHGs), and cooperatives' decision-making capacities to enable them to own and drive climate-resilient initiatives.

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- Promote Inclusivity: Facilitate active participation of women farmers, rural youth, and marginal communities in all phases—planning, implementation, and monitoring—so that benefits are shared equally.

Source: https://www.campusforcommunities.org/community-led-planning

3. Steps in Developing a Community-Led Climate Action Plan

Development of a Community-Led Climate Action Plan (CLCAP) is a formal, participatory process to make sure that interventions are locally appropriate, socially inclusive, and technically robust.

1. Community Mobilization

The process starts with community outreach through village meetings, awareness campaigns, and participatory workshops. Trust and active participation are generated during this phase. Setting up Farmer Interest Groups (FIGs) or specific climate committees provides coordinated representation and decision-making ability.

2. Vulnerability Assessment

Communities evaluate historical climate trends, crop damage, pest epidemics, and water resource patterns. Participatory Rural Appraisal (PRA) methods, Geographic Information System (GIS) mapping, and farmer consultations are utilized to collect both scientific and local information.

3. Prioritization of Climate Risks

Possible risks like droughts, floods, heatwaves, and infestations are enumerated and prioritized based on frequency, intensity, and livelihood impacts.

4. Adaptation and Mitigation Strategy Design

Adaptation: Implementation of drought-resilient varieties of crops, precision irrigation, mulching, and diversification of crops.

Mitigation: Implementation of agroforestry, conservation tillage, adoption of renewable energy, and soil carbon sequestration.

5. Alignment with Local Development Plans

The CLCAP is integrated with Panchayat Development Plans, watersheds, and central/state agricultural schemes like PM-KUSUM, PMKSY, and NMSA, to ensure convergence of resources and policy support.

6. Implementation and Capacity Building

Interventions are carried out by means of farmer field schools, demonstration plots, and exposure visits to allow experiential learning and skill acquisition.

7. Monitoring, Evaluation, and Learning (MEL)

Progress is monitored through measurable indicators—crop yield, income, efficiency use of resources and the plan is annually updated and reviewed based on outcome and community feedback.

4. Core Components of CLCAP in Agriculture

A Community-Led Climate Action Plan (CLCAP) for agriculture involves several integrated elements to address both adaptation and mitigation objectives and ensure long-term sustainability.

4.1 Climate-Smart Crop Planning

Seasonal crop calendars are prepared based on local weather forecasts, agro-advisories, and past climate data. This assists in synchronizing sowing, harvest,

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and input application with good conditions. Encouragement of drought- and flood-tolerant and short-duration crop varieties minimizes yield losses under conditions of uncertain weather. Inter-cropping and rotation are promoted to retain soil fertility and diffuse risk.

Source:https://csaguide.cgiar.org/csa/what-is-climate-smart-agriculture

4.2 Soil and Water Conservation

The measures include contour bunding, check dams, farm ponds, and percolation tanks, which save water and also decrease erosion. Micro-irrigation techniques such as drip and sprinkler irrigation make efficient use of water. Green manures and organic mulches increase soil organic matter, with enhanced moisture content and relief from temperature stress for crops.

4.3 Agroforestry and Biodiversity

Incorporating multi-purpose trees on farms is providing shade, fodder, fuelwood, and carbon sequestration. Conservation of on-farm biodiversity—such as native crop varieties, wild species, and pollinator plants—is buffering climate shocks and pest attacks.

4.4 Renewable Energy and Mechanization

Use of solar-powered irrigation pumps, bioenergy units, and other renewable energy technologies lowers dependence on fossil fuels. Energy-efficient farm machinery reduces greenhouse gas emissions and lessens drudgery.

4.5 Integrated Pest and Nutrient Management

An integrated strategy that includes biopesticides, neem-based products, pheromone traps, and habitat manipulation minimizes the use of chemical pesticides. Balanced fertilization using biofertilizers and micronutrients maintains soil health while providing nutritional sustainability without degrading soil health.

5. Role of Stakeholders

Stakeholder	Role in CLCAP
Farmers	Lead planning, adopt practices, share knowledge
Self-Help Groups	Mobilize women farmers, manage micro-credit
Panchayats	Integrate CLCAP into local development plans
Krishi Vigyan Kendras (KVKs)	Provide technical training and demonstrations
NGOs/CSOs	Facilitate participatory planning and monitoring
Private Sector	Supply climate-resilient inputs and market linkages
Research Institutions	Develop region-specific climate-resilient technologies

6. Benefits of Community-Led Climate Action in Agriculture

Local climate action in agriculture enables farming communities to own their adaptation and mitigation efforts, and this results in several social, economic, and environmental advantages.

Increased Resilience: Through joint risk assessment and the application of localized measures, communities are more equipped to withstand climate

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shocks like floods, droughts, and heatwaves. Early warning systems, diversity in crops, and risk management through instruments such as community grain banks decrease vulnerability.

Enhanced Productivity: Use of climate-resilient crop varieties, integrated pest management, and sustainable agronomic practices improves yields. Farmer-to-farmer transfer increases technology uptake, such that smallholders also get to enjoy innovations.

Environmental Sustainability: Group water management, precision farming methods, and conservative application of fertilizers and pesticides minimize wastage. This not only reduces the cost of production but also decreases environmental degradation.

Social Inclusion: Marginalized groups such as women, landless farmers, and tribal farmers are encouraged to participate through community-led initiatives. Such inclusive decision-making increases equity and enhances social cohesion.

Market Benefits: Improved quality of produce, enhanced post-harvest handling, and value addition opportunities enable farmers to sell at premium markets. Produce aggregation by farmer collectives enhances bargaining power and minimizes reliance on exploitative middlemen.

Environmental Benefits: Climate action plans encourage the rejuvenation of soil health using organic amendments, cover crops, and conservation tillage. Conservation of biodiversity, agroforestry, and reduced chemicals help maintain ecosystem equilibrium. Furthermore, actions such as the use of biochar and planting trees help increase carbon sequestration in support of international climate mitigation efforts.

7.Implementation Challenges

In spite of the great potential of Community-Led Climate Action Plans (CLCAPs) in changing farming in response to climate change, there are a number of challenges to effective implementation. One of the main limitations is the shortage of technical know-how among farmers for climate-smart farming methods like precision irrigation, integrated pest management, soil carbon sequestration, and diversification of crops. Most farmers do not know these methods, which need demonstration and specialized training to urge farmers to take them up.

Another critical barrier is the lack of funding for large-scale adoption. Pilots tend to yield good results, but scaling up demands huge investments in inputs, training, and infrastructure. Smallholder farmers, especially, are constrained by limited finance, which prevents them from adopting climate-resilient practices without either subsidies or credit access.

Inadequate rural internet and ICT facilities in many parts also restrict the application of weather prediction tools, market connectivity, and remote advisory services. This constrains timely access to information for climate adaptation planning.

Coordination deficits among government departments and stakeholders also hinder effective action. CLCAPs need the direct participation of agricultural, water, forestry, and rural development agencies, but non-integration often results in duplication of efforts or lost opportunities for synergy.

Lastly, there is the difficulty in maintaining community participation in the long run. Initial excitement may be strong, but sustained participation depends on tangible returns, effective leadership, and robust institutional mechanisms. In the absence of sustained motivation and stake, community-driven programs tend to suffer from loss of momentum in the long run. Overcoming these challenges will call for an integrated approach that incorporates technical capacity-building, financial incentives, policy integration, and long-term participatory governance.

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8. Way Forward

The potential of Climate-Smart Agriculture (CSA) and Climate-Linked Community Agricultural Planning (CLCAP) in the future is to build a strong framework that brings together technology, finance, capacity building, and policy. Improved digital climate services using mobile-based weather forecasts, agro-advisories, and early warning systems can help farmers make real-time decisions. Integration of climate finance is required to provide farmers with access to green credit, low-interest loans, and integrated insurance products that cover against climate-related losses.

Capacity building must be ongoing, comprising on-the-job training, demonstration in the fields, and exposure tours to exemplary CSA projects, thus establishing long-term capabilities. Targeted attention to youth and women's involvement can generate a new generation of "Climate Champions" as local leaders who promote adaptive agriculture practices and galvanize communities.

At the policy level, mainstreaming CLCAP into national and state agricultural policies will make its adoption institutionalized. Governments must promote inter-departmental cooperation, public–private partnerships, and incentives for the uptake of CSA practices. Through integration of digital tools, financial mechanisms, human resource development, and solid policy support, the path forward will not only provide climate shock resilience but also ensure sustainable agricultural development. This holistic approach has the potential to change rural livelihoods while conserving natural resources for generations to come.

9. Conclusion

Community-Led Climate Action Plans for agriculture fill the gap between policy intention and reality at the field level. By letting farmers themselves detect local climate vulnerabilities and craft adaptive responses, CLCAPs ensure that the solution is locally appropriate, socially equitable, and environmentally friendly. By incorporating innovative climate-smart technology and indigenous knowledge, CLCAPs can be a game-changer for establishing resilient agricultural communities and securing food safety in a changing climate.

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Capacity Building of Extension Workers in Post-Harvest

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Post-harvest assessment capacity building of extension workers is crucial to reduce post-harvest losses and enhance farmers' income. Training programs on handling, storage, quality evaluation, and value addition impart functional competence and relevant knowledge. Institutional linkages strengthened, resource centers developed, and certification promoted ensures efficiency and credibility. Public–private partnership, policy support, and assurance ensure sustainability. Through the strengthening of extension workers with technical know-how and advanced tools, the agricultural value chain can be fortified for improved market access, less wastage, and enhanced livelihood opportunities for rural communities.

Introduction

The value chain of agriculture stretches much beyond the harvest, involving storage, processing, transport, and marketing. Poor post-harvest management ends up costing a significant amount of losses, especially in developing nations such as India. It has been estimated that cereals incur 5–10% losses, pulses 8–10%, while fruits and vegetables are able to incur astronomical losses of 20–40%. These losses not just lower the availability of food but also erode farmers' incomes and increase market inefficiencies.

Extension workers serve as critical linkages between research centers and farming communities, guaranteeing timely release of best practices and innovations. Capacity development in post-harvest loss estimation enhances their capacity to detect loss points, implement suitable prevention measures, and advocate for safe handling, storage, and processing practices. Providing extension workers with appropriate tools, methods, and hands-on training can improve food quality and safety, minimize wastage, and increase profitability for farmers—leading to sustainable agricultural development and food security.

2. Capacity Building Objectives

The key aim of capacity building among extension workers in post-harvest appraisal is to enhance their technical expertise, analytical abilities, and advisory skills to properly minimize post-harvest losses and enhance agricultural value chains.

- Increase reproducible knowledge of post-harvest handling, grading, and storage: Provide extension workers with in-depth knowledge of crop-specific handling practices, grading levels, and scientifically appropriate storage practices to ensure quality and minimize spoilage.
- Improve qualitative and quantitative estimation of losses: Train them to estimate both visible (weight, volume) and invisible (nutritional, quality) losses accurately, enabling accurate data collection for informed decision-making.
- Cultivate tools and methods of post-harvest measurement: Acquaint extension workers with new instruments, digital devices, and standard procedures for evaluating losses during harvesting, transit, and storage.

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- Encourage best practices to prevent loss and preserve quality: Inspire use of low-cost, environmentally friendly technologies and practices like effective drying, packaging, pest management, and moisture control.
- Enhance advisory ability for interventions at the farmer level: Equip extension workers to offer location-specific advice to farmers, blending traditional wisdom with novel innovations.
- Foster market-driven strategies and value addition: Encourage producer-market linkages, focusing on value-added processing, better packaging, and brand building to improve farmers' incomes and minimize wastage.

Source: https://www.frontiersin.org/journals

3. Significance of Post-Harvest Assessment

3.1 Economic Importance

Post-harvest evaluation is an essential tool in the reduction of economic losses through the elimination and minimization of preventable wastage of agricultural commodities. Storage, handling, and transportation losses can greatly reduce farmers' earnings as well as the availability of food in the country. Proper assessment guarantees improved grading, sorting, and packaging, which increases the market value of products. The extension of shelf life and preservation of quality enables producers to obtain premium prices and access domestic and export markets. This not only enhances profitability but also enhances stability in the agricultural economy.

3.2 Food Safety & Quality

Post-harvest inspection guarantees the safety and quality of produce, which is a critical component. It identifies physical damage, microbial contamination, or chemical residues that may harm consumer health. By systematic assessment, produce can be kept in line with national and international food safety requirements to support access to high-value export markets. Quality evaluation maintains nutritional value, taste, and appearance, which has a direct effect on consumer acceptability. Regular quality control instills confidence among consumers and enhances brand image for producers and exporters as well.

3.3 Environmental Impact

Post-harvest evaluation makes a contribution towards environmental sustainability by minimizing the loss of food. When fruits and vegetables are lost following harvest, not only are the crops lost, but also the inputs—such as water, fertilizer, and power—invested in cultivating them. Additionally, the breakdown of farm waste in landfills releases greenhouse gases, which lead to climate change. Through the extension of the period for which crops are usable by means of improved handling and storage, evaluation minimizes the demand for overproduction, thus preserving natural resources. This is aligned with international sustainable development objectives, encouraging sustainable consumption and production.

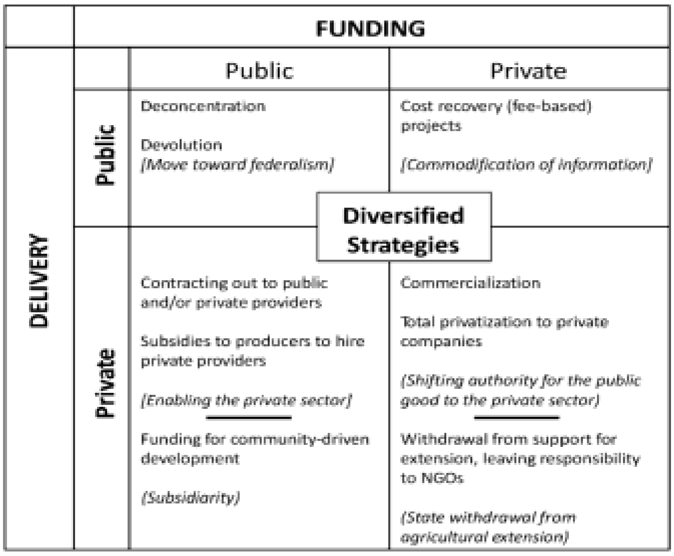
4. Key Elements of Training for Extension Agents

4.1 Post-Harvest Physiology

Extension workers need to first understand the physiological processes that occur subsequent to crop harvesting. Training involves crop maturity indices to identify the best time for harvesting, the respiration rates and ethylene production that affect ripening, and the physiological maturity stages of various commodities. The contribution of moisture content in affecting storage life, susceptibility to pests, and the degradation of quality is also highlighted as a key aspect of loss prevention.

4.2 Loss Assessment Methods

Employees are instructed in quantitative procedures like weight loss measurement and sample-based estimation to measure the percentage of losses. Visual grading for physical damage, sensory evaluation for texture and flavor, and laboratory analysis for microbial contamination and chemical residues are among the qualitative methods. Proper sampling procedures guarantee that data obtained is representative of the bulk consignment, and this is crucial for credible assessments.



Source: https://www.mdpi.com

4.3 Storage and Handling Practices

Training promotes reducing loss by proper harvesting techniques to minimize bruising, cutting, and mechanical damage. Size, color, and quality sorting and grading prepares the produce for market. Packaging requirements address cushioning, ventilation, and labeling. Storage modules encompass traditional facilities (e.g., mud bins, bamboo cribs) and modern facilities (e.g., cold storage, controlled atmosphere units) as well as maintenance guidelines. For perishables, temperature and humidity control procedures are illustrated to extend freshness.

4.4 Application of Tools and Equipment

Hands-on training exposes personnel to grain moisture meters, digital weighing scales, and quality grade charts to achieve proper, standardized evaluations. Innovative mobile-based loss estimation applications are presented for real-time data recording and reporting to enhance monitoring efficiency.

4.5 Documentation and Reporting

Extension workers are educated in standardized data recording formats for loss assessment and post-harvest loss monitoring systems to analyze trends over time. They are also educated in the preparation of farmer-level advisory documents with corrective actions for problems identified.

5. Steps for Capacity Building Implementation

1. Needs Assessment

The first step involves identifying the skill gaps among existing extension personnel. This can be achieved through surveys, interviews, and focus group discussions with both extension workers and farmers. A baseline assessment of current knowledge levels, technical competencies, and exposure to post-harvest practices helps in tailoring the training program to the real needs of the workforce.

2. Training Module Development

According to the gaps that have been established, locally applicable, commodity-specific modules are prepared. The modules blend scientific know-how with field practical solutions. The material must cover handling, storage, loss evaluation, and quality management. Practical demonstrations, actual case studies, and farmer stories of success are added to ensure learning becomes practical and effective.

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3. Training Delivery

Training is imparted through field-level workshops, demonstrations at the work site, and classroom lectures. Partnerships with Farmer Producer Organizations (FPOs), cooperatives, and Krishi Vigyan Kendras (KVKs) increase outreach and involvement. Extension workers learn first-hand to work with tools, sort produce, and use loss prevention techniques in actual farm settings.

4. On-the-Job Mentoring

To guarantee long-term skill deployment, newly graduated extension workers are assigned experienced mentors. The mentors guide them on farm visits, assist in problem-solving in the field, and exchange best practices. Routine performance assessments and feedback meetings monitor progress and fill gaps timely.

5. Digital Integration

Technological aids like mobile apps, e-learning modules, video tutorials, and WhatsApp advisory groups are incorporated in the capacity building process. ICT-based platforms offer constant learning opportunities and ensure extension workers are exposed to current information on post-harvest technologies, storage innovations, and market trends.

6. Impact Assessment

Upon implementation, adjustments in farmer behavior and post-harvest loss reduction are quantified. Surveys, on-site visits, and assessments of yields in terms of quality are undertaken. Both farmer and extension staff feedback serve to update and enhance training materials to ensure relevance and effectiveness in the long term.

6. Post-Harvest Capacity Building Challenges

Post-harvest capacity development among extension workers is essential in minimizing losses, enhancing quality, and increasing farmers' incomes. Yet, there are numerous challenges that impair its efficiency. A significant challenge is that many extension workers have a limited technical background and lack comprehensive information about contemporary post-harvest handling, grading, and processing methods. Access to sophisticated post-harvest technology—e.g., cold storage facilities, moisture meters, and packaging machinery—is also low, especially in rural and resource-poor settings.

Deficient infrastructure—weak transportation, storage, and market access—exacerbates the issue, creating high perishability and lower value of produce. Low levels of awareness by farmers regarding the significance of post-harvest management cause poor adoption rates even when technologies are made available. Inefficient linkages among research institutes, extension services, and markets restrict transfers of innovations as well as farmer-oriented solution development.

Eradicating these challenges needs holistic training programmes, rural infrastructure investment, improved research–extension–market linkages, and knowledge sharing using digital technologies. Improving these areas can dramatically enhance post-harvest results, decrease losses, and benefit profitability for farming societies.

7. Best Practices & Success Models

Case Study 1 – Grain Loss Reduction in Madhya Pradesh

In rural areas of Madhya Pradesh, post-harvest grain loss was a chronic problem, frequently doubling as a percentage point due to inadequate storage and unregulated levels of moisture. With a focused capacity-building initiative, extension agents provided training to farmers on how to use hermetic storage bags and affordable moisture meters. In village clusters, they organized demonstrations, illustrating that proper drying and monitoring of moisture avoid mold development and pest attacks. Within only two crop seasons, tangible gains were registered—grain loss declined by 18%, and household food security significantly improved. This intervention demonstrated how locally applicable, low-cost solutions could make a big economic and nutritional difference.

Case Study 2 – Adoption of Cold Chain in Maharashtra

In Maharashtra's grape and tomato belts, post-harvest wastage while transporting to urban markets frequently resulted in substantial wastage and lower farm revenues. A post-harvest handling, pre-cooling practices, and cold chain logistics specialized training program for extension workers. Farmers were educated on correct harvesting maturity, grading, and packaging to match cold storage utilization. Shelf life was increased by 7–10 days due to this intervention, giving farmers the ability to strategically schedule their sales. The intervention resulted in an average 25% market price increment and minimized transport losses. The case is a demonstration of how integration of technical knowledge with market access strategies can reshape the economics of the value chains of perishable crops.

8.Recommendations for Effective Capacity Building

It is essential to strengthen research institutional-extension agency linkages for sharing the latest knowledge. Setting up Post-Harvest Resource Centers at block and district levels will make support localized. Certification schemes for trained extension workers can improve credibility and skill recognition. Public–private partnerships need to be encouraged for infrastructure and resource development. Moreover, providing sustained policy support and sufficient funding will allow constant capacity building. All these in tandem will enhance the effectiveness of extension workers in post-harvest evaluation, minimize losses, and benefit farmers' profitability in terms of improved handling, storage, and market connectivity.

9. Conclusion

Reduction of post-harvest loss is crucial for food security, improvement of farmer income, and environmental sustainability. Equipping extension workers with scientific information, new tools, and hands-on skills guarantees that they are able to provide effective advisory services to farmers. An effective capacity-building program has the potential to convert post-harvest management from an overlooked phase to a key node in the agricultural value chain.

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Soil Saviors: Trichoderma and Allies in Onion Protection

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Introduction

The onion (*Allium cepa. L*), which belongs to the family, Amaryllidaceae is one of the most important bulbous crops produced worldwide. The Latin term for "large pearl" is "onion." Its form and nutritional value are comparable to those of pearl. Around the world, 23.28 million tons of onions are produced annually. India is a significant onion grower, ranking second in the world for onion production. In 2018–19, India exported 24,40,741.9 thousand MT of onion, with a total worth of Rs 352205.34 Lakhs. This indicates that India cultivates onion as a valuable vegetable crop.

Basal rot in onions is caused by the dangerous fungal pathogen *Fusarium oxysporum* f. sp. *cepae*. During the seedling stage, it can result in a 90% yield loss, and during storage, it can cause a 30% yield loss. The symptoms are leaf yellowing and tip-down leaf drying. The roots initially display a pink colour, which eventually decomposes. The rot occurs in the basal plate at the advanced stage, and the entire plant perishes. The ideal temperature for disease incidence is between 35 and 40 degrees Celsius, with a relative humidity of 70%.

Chemical fungicides such as carbendazim, thiram, etc. harm the soil and destroy the soil biome. Continuous exposure to these chemicals can lead to their biomagnification, potentially causing chronic illnesses and genetic abnormalities in future generations. Globally, there is a growing shift towards alternatives to chemical pesticides, driven by concerns over their environmental and health impacts. One such alternative is the use of microbial biocontrol agents to manage pests, diseases, and weeds. They offer a sustainable, eco-friendly solution by targeting specific pests without harming beneficial species, making them an essential part of integrated pest management.

SYMPTOMS AND YIELD LOSS:

Fusarium Basal Rot (FBR), caused by *Fusarium oxysporum f.* sp. *cepae* is an important disease affecting onion cultivation in India. The pathogen primarily targets the roots and basal plate of the bulb, leading to symptoms that range from minor root rot and discoloration to complete necrosis of the basal tissues. In the field, early signs include yellowing and browning of leaves, starting from the tips and progressing downward. Infected plants often show poor growth, become weak, and may eventually wilt. As the disease progresses, the fungus penetrates deeper into the bulb, resulting in the decay of internal scales. In some cases, bulbs may appear healthy at harvest but harbor latent infections, which later manifest as rot during storage. Further, the severity and incidence of *Fusarium* basal rot tend to increase significantly during post-harvest storage, posing a major challenge to onion preservation and marketability.

This disease is prevalent in high-moisture and high soil-temperature conditions and the symptoms are observed in most of the fields. Infection occurs at soil temperatures of 15 °C to 32 °C, with an optimum at 28 °C - 32 °C, as infection and disease development is favoured by high soil temperature (Mishra *et al.*,

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2014). The analysis of weather parameters in relation to the intensity of basal rot disease in onions revealed a significant positive correlation with overall temperature and sunshine hours.

Analysis of available data on basal rot incidence from 1998 to 2022 revealed that the prevalence of FBR ranged from 11% to 50%. During Kharif 2022, the disease incidence was observed to range between 27.09% and 38.83% (Thakare *et al*., 2023) . In Tamil Nadu, onion is cultivated on about 54,000 ha, mainly in the districts of Perambalur, Namakkal, Tiruchirappalli, and Dindigul (www.newindianexpress.com 2021). FBR is recognized as an economically significant disease of onion. It can cause yield losses of up to 50% in the field and 30–40% during postharvest storage of bulbs. A study conducted by (Sintayehu et al., 2011). further substantiated its economic impact, confirming that the disease severely affects both production and storage quality.

FUNGAL BIOCONTROL AGENTS

Fungal biocontrol agents offer several advantages over chemical fungicides. They are environmentally safe, biodegradable, and promote sustainable agriculture by improving soil health and enhancing microbial diversity. Among these, *Trichoderma* spp., *Aspergillus* spp., *Penicillium* spp., and *Gliocladium* spp. are recognized for their efficacy against FBR in onions. Of these, *Trichoderma* spp. are the most widely used commercial biocontrol agents for managing FBR. Species such as *T. harzianum*, *T. viride*, and *T. asperellum* have demonstrated high efficacy against *Fusarium oxysporum*. The maximum growth inhibition of the fungal pathogen was induced by *T. viride* (95.5%) and *T. harzianum* (92.6%) followed by *P. fluorescens* (88.3%) and *B. subtilis* (79.3%), respectively (El-Mougy *et al.,*2019). These species aggressively colonize the rhizosphere, produce antifungal compounds, and stimulate plant growth.

In addition to managing FBR, Trichoderma spp. enhance soil health, improve plant resilience to environmental stresses, and suppress other important onion pathogens. For instance, *T. harzianum* and *T. viride* inhibit sclerotia germination, restrict mycelial growth, and reduce lesion development on leaves caused by *Alternaria porri.* This broad-spectrum activity makes *Trichoderma spp.* a valuable component of integrated disease management strategies in onion cultivation.

MODE OF ACTION:

Trichoderma is a popular symbiotic fungus that inhibits or controls the Fusarium wilt through the mechanism of mycoparasitism, completion, production of various lytic enzymes, and other antimicrobial activities along with enhancement in the growth of the host plant by the production of plant growth hormones. Mycoparasitism begins with the recognition and attachment of *Trichoderma* hyphae to the pathogen, followed by coiling and the formation of appressoria, structures that help penetrate the host using high osmotic pressure and enzymes like chitinases, glucanases, and proteases. These enzymes break down the fungal cell wall, allowing *Trichoderma* to invade and absorb nutrients. Additionally, *Trichoderma* produces antifungal secondary metabolites such as peptaibols, polyketides, and viridiofungins, which inhibit pathogen growth. It also competes effectively for nutrients and space due to its rapid growth and adaptability, often outcompeting *Fusarium* in the rhizosphere.

Beyond direct antagonism, *Trichoderma* activates plant defense mechanisms through induced systemic resistance (ISR) and systemic acquired resistance (SAR). It enhances hormone signaling pathways involving jasmonic acid (JA), salicylic acid (SA), and ethylene (ET), which stimulate defense gene expression such as PR1a, PR2, PR3, and PDF1. Furthermore, it modulates reactive oxygen species (ROS) levels, reducing oxidative stress during infection. These combined actions lead to lower disease incidence and severity in onions and other crops, highlighting *Trichoderma* as an effective and eco-friendly biological control agent against Fusarium wilt.

MODE OF APPLICATION:

1. Seed Treatment:

Seed treatment is an effective and economical method for providing early protection against Fusarium oxysporum in onion. This practice involves coating onion seeds with fungal biocontrol agents such as *Trichoderma harzianum* or *T. asperellum*. These beneficial fungi colonize the seed surface and the emerging root system, forming a protective barrier that prevents early-stage infection by soil-borne pathogens. The bioagent is typically applied at the rate of 4–5 g per kilogram of seed. The seeds are slightly moistened, mixed thoroughly with the fungal formulation, and shade-dried prior to sowing. This ensures that antagonistic fungi are present from the time of germination, enhancing seedling vigor and suppressing the pathogen at its initial point of contact. In addition to disease suppression, seed treatment with *Trichoderma* spp. reduces the reliance on chemical fungicides, making it a safe, eco-friendly, and sustainable component of integrated disease management strategies in onion cultivation.

2. Root Dip Treatment:

Root dip treatment is a widely adopted practice during the transplanting of onion seedlings from the nursery to the main field. In this method, seedlings are immersed in a suspension of fungal biocontrol agents prepared by mixing *Trichoderma* spp. at a rate of approximately 10 g per liter of water to form a uniform slurry. The roots are dipped in this solution for 20-30 minutes, enabling the fungal bioagents to adhere to the root surface and initiate colonization of the rhizosphere. This direct application effectively suppresses Fusarium spores present in the soil and provides immediate protection to the vulnerable root tissues during the critical transplanting stage. In addition to controlling the pathogen, root dip treatment minimizes transplant shock, enhances plant immunity, and promotes better establishment and early growth. The method is particularly beneficial in *Fusarium*-prone fields and can be integrated with organic soil management practices to achieve improved disease suppression and sustainable crop production.

3.Soil Application:

Soil application is an important preventive strategy for managing *Fusarium oxysporum* f. sp. *cepae*, particularly in fields with a known history of wilt incidence. This method involves the incorporation of fungal biocontrol agents, such as *Trichoderma harzianum* or *T. viride*, directly into the soil before transplanting. Typically, 2.5-5 kg of the biocontrol agent is thoroughly mixed with 50-100 kg of well-decomposed farmyard manure (FYM), compost, or vermicompost. The enriched mixture is then broadcast evenly over the field and lightly incorporated into the topsoil, preferably 7-10 days prior to planting. This practice ensures the establishment of beneficial fungi in the rhizosphere, enabling early suppression of soil-borne pathogens and promoting healthy crop establishment.

4.Drip Irrigation:

Drip irrigation offers a modern and efficient approach for delivering fungal biocontrol agents directly to the onion rhizosphere, ensuring precise and uniform coverage. Liquid-based formulations of beneficial fungi such as *Trichoderma harzianum* and *T. viride* are commonly employed for this purpose. Recommended commercial products include TNAU *Trichoderma* Liquid, Biotrich-L, and Ecofit. The standard application rate is 5–10 ml per liter of water, with the biocontrol solution delivered through the drip system at 15–20-day intervals, beginning 15 days after transplanting. In regions with high disease pressure or sandy soils, more frequent applications may be warranted. Through the moisture channels

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created by the drip lines, the bioagents effectively colonize the root zone and suppress *Fusarium oxysporum* f. sp. *cepae*, thereby reducing disease incidence and supporting healthy crop growth.

Conclusions:

Fusarium basal rot (FBR) is a major constraint in onion production, causing substantial yield losses both in the field and during postharvest storage. With increasing concerns over the adverse environmental and health impacts of chemical fungicides, fungal biocontrol agents such as Trichoderma spp. have gained attention as effective and eco-friendly alternatives. These beneficial fungi suppress Fusarium through mechanisms including mycoparasitism, competition for nutrients and space, production of lytic enzymes, and induction of plant defense responses. A range of application methods such as seed treatment, root dip, soil incorporation, and drip irrigation with Trichoderma-fortified compost have demonstrated promising results in reducing disease incidence and improving onion yield. When applied systematically, these methods establish beneficial fungal populations in the rhizosphere, providing continuous protection against soil-borne pathogens throughout the crop cycle.

Beyond disease control, the use of fungal biocontrol agents enhances soil health, promotes plant vigor, and improves resilience to environmental stresses. Integrating these practices into onion cultivation not only reduces dependency on synthetic chemicals but also supports sustainable production systems, contributing to long-term farm profitability and environmental conservation.

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Vertical Farming & Hydroponics as Urban Agriculture Solutions

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Urbanization and population expansion have increased the need for food production in cities. Challenges to traditional agricultural methods include resource depletion, climate change, and a shortage of available land. Vertical farming and hydroponics provide creative answers to these problems by facilitating high-yield, sustainable food production in urban settings using cutting-edge technology, including precise fertilizer delivery, controlled temperature management, and LED lighting. By cultivating crops indoors, vertical farming reduces exposure to pests, illnesses, and harsh weathering precise fertilizer delivery, controlled temperature management, and LED lighting. Vertical farming reduces exposure to pests, illnesses, and harsh weather by cultivating crops indoors, guaranteeing steady and superior harvests all year long. By supplying nutrient-rich water solutions straight to the roots, hydroponics, a soilless farming method, promotes plant development. By reducing food miles, carbon footprints, and dependency on chemical fertilizers and pesticides, the combination of hydroponics with vertical farming in urban agriculture promotes environmental sustainability. Additionally, by promoting regional food production, these systems enhance metropolitan populations' access to fresh produce and food security. Notwithstanding these benefits, issues including high upfront expenditures, energy usage, and the need for technical know-how need to be resolved. The viability and scalability of urban farming solutions may be improved by developments in cost-effective technology, regulatory assistance, and the incorporation of renewable energy.

Introduction

Global population expansion and urbanization have raised the demand for sustainable food production technologies. Al-Meselmani (2024). Conventional agriculture has limits, such as decreasing arable land, climate variability, and water scarcity. Benke and Tomkins, (2017). Furthermore, typical agricultural operations are resource-intensive, as they require enormous inputs of water, fertilizers, and pesticides, which can be harmful to the environment in the long term. Rajaseger *et al.*, (2023). Aeroponics and hydroponics enable year-round production and reduce crop losses. Furthermore, the agricultural sector is currently plagued with workforce shortages, logistical inefficiencies, and the unpredictability of weather patterns caused by climate change. Magwaza *et al.*, (2020). Hydroponics provides numerous benefits, but some drawbacks must be overcome in order for it to be used properly. Main of them includes the cost at the time of its preliminary setting, technicality level, and the large use of energy. Further nutrient management and disease prevention become critical factors to keep optimal crop yield in the system of hydroponic cropping Khatri *et al.*, (2024). This technique holds much promise to overcome numerous drawbacks associated with conventional land-based farming. The ability to grow plants in controlled environments offers invaluable opportunities to increase food productivity, especially in urban contexts where arable land access is limited Sharma *et al.*, (2023). Hydroponics and vertical farming have recently come into the limelight as the best alternatives for vegetable cultivation in this scenario Reddy *et al.*, (2022).

2.Challenges in Urban Food Production

Fluctuating market trends all respondents stated that their choice of veggies for growing was heavily influenced by market prices for vegetables. For example, they decided to cultivate bird chilies (capsicum annuum) when the market price surged and demand was high. At the time of writing, bird chilies were priced at rm18.00 per kg wholesale and rm20.00 per kg as indicated . However, during the chinese new year season, the retail price of chilies increased to rm50 or even up to rm100 per kg due to a decrease in supply induced by meteorological conditions. Bird's eye chilies used to cost between rm20 and rm30 per kg, but the short age has pushed the price up to rm50 per kg."

Competition from traditional farmers and imported goods Respondents reported significant competition from both conventional farmers and imported agricultural items. Conventional farmers often have a lengthy family agricultural ancestry and use traditional farming practices. This convention contrasts from the majority of respondents involved in hydroponics and VF. Instead of employing trial and error methods, they are compelled to start over and do research and development (R&D) to boost crop productivity while minimizing resource waste. R&D is crucial for hydroponic and VF practitioners to improve farming practices, adapt to local conditions, and ensure sustainability. From our observations, R&D played a crucial role for these hydroponic and VF practitioners as such efforts contributed to enhancing farming practices, enabling a high degree of adaptability to dynamic localized environmental circumstances, and ensuring the sustainability of agricultural operations for them to remain relevant and competitive in the market.

1. Innovative Solutions in Urban Agriculture

Current technological developments have transformed the hydroponics and vertical farming systems into more efficient, sustainable, and adaptable technologies to the needs of agriculture today Kabir *et al*., (2023).

3.1 Energy-Efficient LED Lighting

More advanced and energy-efficient LED innovations now allow for lighting that are tailored to your plants' unique needs (Benke and Tomkins, 2017). LEDs may now be programmed to generate certain wavelengths of light, enhancing photosynthesis during various growth stages. They also emit less heat, lowering cooling requirements; this allows them to get even closer to the plants, maximizing space use Erekath *et al*., (2024).

3.2 Automated Nutrient Delivery Systems

Innovations in automated nutrient management introduced systems that can continuously monitor and make adjustments in real-time Halgamuge *et al*., (2021). These systems use sensors that track pH levels, electrical conductivity (EC), and nutrient concentrations to ensure that there is optimal nutrient availability without waste.

3.3 Artificial Intelligence (AI) and Machine

Machine learning (ML) AI and machine learning have actually become important to predictive agricultural models in hydroponics and vertical farming (Rathor *et al*., 2024). AI takes environmental data and predicts crop yield, identifies potential issues relating to nutrient deficiencies or a pest threat, and provides optimization of resource usage, such as computer vision technology detection of early signs of plant stress and disease, which can bring timely interventions. Rajendiran and Rethnaraj (2023).

3.4 Integration of Renewable Energy Sources

Renewable energy integration is reducing the carbon footprint of these systems. Solar panels and wind turbines are increasingly used to power vertical farming operations Vatistas *et al*., (2022). Battery storage systems ensure that energy is available during off-peak hours, making the systems more self-sufficient and sustainable Sahoo, and Timmann, (2023).

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4. Benefits of vertical and hydroponics system

Hydroponics and vertical farming systems have many advantages over traditional farming methods:

4.1 Resource Efficiency

These systems consume much lesser resources. Hydroponics saves up to 90% of water, as the nutrient solution is recycled Rufí-Salís *et al.,* (2020).

4.2 Space Optimization

These systems make maximum use of the available space vertically Touliatos *et al.,* (2012). These systems are perfect for cities where land is scarce Taylor *et al.,* (2012). The food produced can be locally consumed, which saves on transportation costs and emissions.

4.3 Pesticide-Free Cultivation

In controlled environments, the need for chemical pesticides is virtually eliminated, resulting in cleaner, healthier produce Ragaveena *et al.,* (2021). The absence of pests also reduces crop losses, further enhancing sustainability.

4.4 Consistent Yields

Vertical farming and hydroponics use controlled environments to ensure year-round output regardless of external weather conditions. Duangpakdee *et al*., (2024). This regularity is crucial for ensuring a reliable food supply, particularly in areas with unpredictable weather. Leafy greens and herbs will constitute the backbone of hydroponic and vertical farming due to shorter growth cycles, compact size, and high output per area. Ampim *et al*., (2022).

5. Vertical Farming Technology and Benefits

Vertical Farming Techniques Patrick Blanc, a French physicist and botanist, is credited with pioneering vertical gardens. In 1988, Patrick Blanc patented a method for designing plants that do not require soil and grow erect. The method uses a felt fabric to substitute soil, absorbing and retaining water. The felt layer is bonded to a PVC board using a specific mesh that contains features that maintain the plant's structure. Plants gradually grow into the felt layer. The entire complex has an irrigation system, and the water is dumped into the sewer system or reused. Vertical gardens must include both environmental variables (such as precipitation, wind, snow cover, and insolation) and structural aspects.

6. Hydroponics: Principles and Advantages

Hydroponics Hydroponics is a method of growing food without soil that employs mineral nutrient solutions. The Encyclopedia Britannica defines hydroponics as "the cultivation of plants in nutrient-rich water, with or without mechanical support from an inert medium such as sand or gravel." The phrase derives from the Greek words hydro and ponos, which imply "water working" or "water doing labour." Although the concept of growing vegetables in water is not new, hydroponics has only recently become commercially viable. NASA researchers have found hydroponics as a feasible method for growing food in space. Some of the vegetables they've successfully grown include onions, lettuce, and radishes. Overall, researchers have improved the hydroponic technique by attempting to make it more effective, reliable, as well as productive. Crop production in the absence of soil provides excellent environmental, growth, as well as development control.

7. Environmental Sustainability and Economic impact

Located in urban settings, high-yield urban agriculture is frequently praised for its claimed reduced carbon footprint in comparison to rural food production, mainly attributed to shorter transportation distances, commonly referred as ‘food miles’ (Ceron-Palma, 2012; Specht, 2014).

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8. Challenges and Limitations

8.1 High Initial Costs

Hydroponic or vertical farming systems involve significant investment in infrastructure, equipment, and technology.LED lighting systems, climate controls, sensors, and automation technologies are among the costs required, which might be prohibitively expensive for small-scale farmers with limited resources.

8.2 Energy Dependence

These systems depend on artificial lighting, climate control systems, and automated processes, which tend to incur a high operational energy cost.

9.Conclusion

Hydroponics and vertical farming are transformational techniques to meeting the issues of modern food production. With expanding population, urbanization, and climate uncertainties, these systems provide long-term alternatives to traditional farming by optimizing resources, conserving water, minimizing pesticide use, and ensuring year-round output. LED illumination, automated nutrition supply, AI-based monitoring, and renewable energy integration all contribute to increased efficiency and adaptability. However, high initial prices, technical competence requirements, and energy reliance remain significant issues that must be overcome in order to secure widespread use. Despite these restrictions, hydroponics and vertical farming show enormous promise for ensuring future food supply, especially in metropolitan settings where arable land is rare. With continued innovation and supportive policies, these systems can play a pivotal role in building resilient, sustainable, and climate-smart agricultural models for the future.

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From Knowledge to Prosperity: Financial literacy as a Tool for Customer Empowerment

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"Financial literacy is not just about numbers; it's about empowering people to make informed choices for their future." By
Dr. Raghuram Rajan
(Former RBI Governor)

Financial literacy "Vitta-Siksha" (a term derived from Sanskrit, meaning "financial education") goes beyond knowing numbers. Financial literacy refers to the ability to comprehend financial products, manage personal finances prudently, set achievable life goals, and make well-informed financial choices. Financial literacy enables individuals to confidently and clearly manage the intricacies of finance. It promotes competitive pressure on financial institutions to offer transparent and consumer-friendly services. By improving decision-making skills, financial literacy helps people select financial products that align with their long-term aspirations.

Historically, many customers have remained passive recipients of financial rights. But with globalization, digitization, and increasingly complex financial ecosystems, customers must know *what's available*, *what they can do*, and *how to do it soundly*.

In an era where financial markets are becoming increasingly complex, the need for financial literacy, has emerged as a critical tool for empowering consumers with the knowledge and skills to navigate economic systems, make sound choices, and build a stable financial future.

Financial literacy serves as a crucial link between individuals and financial institutions. Rather than aiming to produce financial experts, it focuses on equipping people with essential skills to make sound financial decisions, fostering trust and effective engagement with financial systems.

This empowerment is particularly crucial for low-income and marginalized groups who face significant barriers, such as limited education and geographic isolation, in accessing banking services. By providing knowledge about financial products like savings accounts, loans, and insurance, *financial literacy* enables consumers to evaluate options, understand risks, and make choices that align with their financial goals.

Individuals with low financial literacy are more likely to face debt issues, engage in high-cost borrowing, and neglect long-term financial planning. *Financial literacy* addresses these challenges by fostering behaviours like budgeting, saving, and timely bill payments, which are essential for maintaining financial stability in volatile economic environments.

The OECD International Network on Financial Education (INFE) published the report "*International Survey of Adult Financial Literacy"* in 2023, highlighting the objectives for the foundation of

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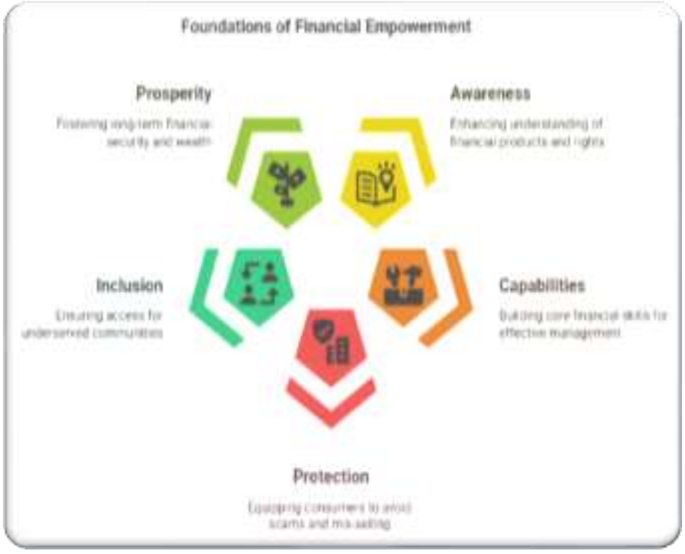
consumers' financial empowerment.



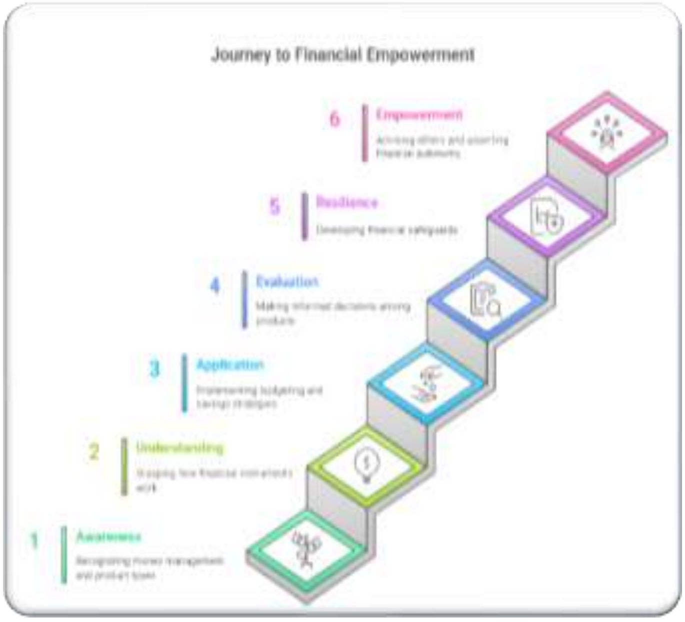
Empowering Consumers Through Financial Knowledge

Financial literacy empowers consumers by providing them with the tools to understand and navigate financial markets. In an era dominated by digital transactions and cutting-edge financial technologies, financial literacy enables individuals to adeptly use these tools, safeguard against fraud, and align their financial choices with personal aspirations. It promotes better financial control, enhances savings habits, supports prudent debt management, and encourages informed investment strategies.

This empowerment is particularly significant, where rapid financial sector growth has introduced complex products like microfinance, mobile banking, and micro-insurance. *Financial literacy* can transform untapped individuals into active economic participants. By providing access to financial knowledge, it enables people to become entrepreneurial, create economic opportunities, and contribute to community development. *Financial Literacy* also promotes long-term economic growth by enhancing the efficiency of financial systems. An informed consumers reduce risks for financial institutions by making prudent financial decisions, which in turn supports the sustainability of financial services. This creates a virtuous cycle where increased financial inclusion drives economic activity, leading to greater prosperity for individuals and communities.

It also encourages financial institutions to provide clearer, more competitive services due to informed consumer demand. A financially literate consumer is more likely to ask critical questions and demand accountability, which strengthens financial markets. By providing individuals with robust financial knowledge, financial literacy empowers them to mitigate risks, protect their financial well-being, and make strategic decisions that bolster long-term economic stability and security.

The journey to financial literacy



❖ ***Awareness: The First Step Toward Financial Consciousness***

The journey of *financial literacy* begins with **Awareness**, where individuals develop a basic recognition of money management and the various financial products available. This stage is about sparking curiosity and opening eyes to the possibilities of financial control. Customers learn to identify fundamental concepts such as income, expenses, savings, and debt. They become familiar with financial instruments like bank accounts, credit cards, and loans, even if the mechanics remain unclear. Awareness is the foundation akin to planting a seed that, with nurturing, grows into financial competence.

❖ ***Understanding: Decoding the Mechanics of Money***

Once awareness is established, the next stage is **Understanding**, where individuals dive into the "how" and "why" of financial instruments. This stage involves grasping the mechanics of key tools such as savings accounts, fixed deposits, or equated monthly instalment (EMI) loans. Customers learn how interest compounds, how loan repayments are structured, and the implications of financial decisions. For instance, they might understand that a high-interest credit card debt can spiral if not managed properly or that a fixed deposit offers stability but lower liquidity. This clarity fosters informed decision-making, transforming abstract concepts into tangible tools for prosperity.

❖ ***Application: Putting Knowledge into Practice***

With understanding comes **Application**, the stage where customers actively implement their knowledge. This is where financial literacy becomes actionable, as individuals create budgets, set up automatic savings plans, manage EMIs, and secure insurance coverages. Application is about bridging the gap between theory and practice turning **"I know" into "I do."** For example, a family might allocate a portion of their income to an emergency fund or choose a health insurance plan that suits their needs. *Financial literacy* empowers customers at this stage by giving them the tools to take control of their financial lives, fostering habits that promote stability and growth. The ability to apply knowledge builds confidence, as customers see tangible results from their efforts, such as reduced debt or growing savings.

❖ ***Evaluation: Making Informed Choices***

The **Evaluation** stage marks a significant leap, where customers develop the ability to compare and choose among competing financial products. This stage is about critical thinking assessing options based on personal goals, risk tolerance, and financial circumstances. For instance, a customer might weigh the benefits of a mutual fund against a fixed deposit, considering factors like returns, liquidity, and risk. By enhancing decision-making abilities, financial literacy enables individuals to choose products that support their long-term financial goals. This stage transforms customers from passive consumers into active participants in the financial ecosystem, capable of navigating complex choices with confidence and clarity.

❖ ***Resilience: Building Financial Safeguards***

Financial literacy reaches a deeper level with **Resilience**, where customers focus on safeguarding their financial future. This stage involves creating robust safety nets, such as emergency funds, understanding the importance of credit scores, and selecting appropriate insurance products. It is to prepare for the uncertainties like loss of job, perhaps some medical emergencies, or economic downturns. For example, a customer might maintain a six-month emergency fund to cover unforeseen expenses or monitor their credit score to secure better loan terms. *Financial literacy* empowers customers by equipping them with the tools to weather financial storms, ensuring they remain on the path to prosperity even in challenging times.

❖ ***Empowerment: Leading and Inspiring Others***

The final stage, **Empowerment**, is the pinnacle of *financial literacy*. Here, financially literate individuals not only manage their own finances with confidence but also become inspiration and influencers within their communities. They advise peers on budgeting, share insights on investment options, and promote responsible financial behavior. Customers who are empowered take charge of their financial choices, aligning their decisions with their personal values and aspirations.

For instance, a financially empowered individual might guide a friend through the process of selecting a retirement plan or advise for financial education in their community.

Understanding personal finance is the basis of empowerment, giving people the knowledge and abilities to confidently manage complex financial matters. It can transform consumers into confident decision-makers, fostering personal and societal prosperity. The value of financial literacy is evident in five critical aspects:

- ✓ Empowerment and Self-Help,
- ✓ Economic Benefits,
- ✓ Trust Building,
- ✓ Fraud Prevention,
- ✓ Resilience in Shocks.

❖ *Empowerment and Self-Help: Taking Control of Financial Futures*

Financial literacy equips individuals with the skills to make smart choices, steer clear of debt pitfalls, and seize opportunities for growing wealth. A financially literate individual can evaluate investment options, such as mutual funds or fixed deposits, to grow their wealth strategically. Financial education fosters self-reliance, enabling consumers to take charge of their financial destinies without depending on intermediaries who may prioritize profit over their interests. For example, a young professional armed with knowledge about compound interest might opt for early retirement savings, setting the stage for long-term prosperity.

❖ *Economic Benefits: Strengthening National Prosperity*

At a macro level, financial literacy drives significant economic benefits, enhancing national savings rates, bolstering capital markets, and reducing non-performing loans. When individuals understand the value of saving and investing, they contribute to a robust pool of domestic capital, which fuels economic growth. Countries with financially literate populations see stronger capital markets, as informed investors diversify their portfolios, supporting businesses and infrastructure development. Moreover, financially savvy consumers are less likely to default on loans, reducing the burden of non-performing assets on banks. For instance, a nation with widespread *financial literacy* might see increased participation in government savings schemes, creating a virtuous cycle of economic stability. By fostering competent savers, financial literacy lays the foundation for collective prosperity, echoing the vision of empowerment outlined in the article.

❖ *Trust Building: Fostering Confidence in Financial Institutions*

Financial literacy fosters confidence between customers and financial organizations. Informed individuals are more likely to engage with banks, insurance providers, and investment firms when they understand the terms of engagement. For example, a customer who comprehends the fine print of a loan agreement or the benefits of a savings product is less likely to feel misled, fostering a sense of partnership with their financial institution. *Financial literacy* empowers customers to ask critical questions and demand transparency, which compels institutions to prioritize ethical practices. This confidence is essential for a thriving financial environment, as it promotes active participation and sustained engagement.

❖ *Fraud Prevention: Shielding Consumers from Scams*

A financially literate populace is a formidable defence against fraud, which remains a significant threat in today's digital age. Data indicates that 15% of adults in OECD countries have fallen victim to financial scams, often due to a lack of awareness

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about common tactics like phishing or Ponzi schemes. *Financial literacy* equips customers with the knowledge to recognize red flags, such as unrealistic investment promises or suspicious requests for personal information.

❖ ***Resilience in Shocks: Navigating Economic Turbulence***

Financial literacy enhances resilience. Economically literate consumers are better equipped to manage their resources during uncertainty, relying on tools like emergency funds, diversified investments, or appropriate insurance coverage. *Financial literacy* empowers customers to anticipate and prepare for shocks, ensuring they remain financially stable even in challenging times. This resilience is important step of the journey from knowledge to prosperity, as it enables individuals to maintain their financial footing and continue building toward their goals.

Financial literacy is a vital tool for equipping customers with the skills to navigate financial systems, make informed choices, and build resilient futures. Global and Indian trends highlight both challenges and progress in this domain, revealing disparities in literacy levels and showcasing transformative initiatives.

Indian Perspective: Progress Amid Challenges

In India, there is a gap in financial literacy particularly pronounced among rural populations, women, and older age groups, where limited access to education and financial services exacerbates disparities. Despite these challenges, India has made remarkable strides in financial inclusion, aligning with the empowerment goals of financial literacy. The Pradhan Mantri Jan Dhan Yojana (PMJDY) has opened over 500 million bank accounts since 2014, bringing millions of unbanked individuals into the formal financial system. Initiatives like the Pradhan Mantri Gramin Digital Saksharta Abhiyan (PMGDISHA) and Common Service Centers (CSCs) have certified around 47 million rural citizens in digital literacy, equipping them to engage with modern financial platforms. These efforts reflect the transformative power of financial literacy, enabling customers to move from exclusion to empowerment through accessible financial tools and knowledge

The Unified Payments Interface (UPI) has transformed the landscape of digital transactions, enabling seamless and efficient payments

This brings to highlight the digital payment innovation, as per the Reserve Bank of India's (RBI) Payments System Report, payments are largely driven by the UPI which was introduced in 2016 by the National Payments Corporation of India (NPCI).

The report also brings out that the UPI has significantly expanded its share in India's digital payment ecosystem, from 34% (2019) to 83% (2024) UPI has shown a great stride. This growth reflects a robust compound annual growth rate (CAGR) of 74% over five years. With a network of 670 financial institutions, as of May 2025, the UPI has processed monthly transactions of more than ₹25 trillion.

Month	No. of Banks live on UPI	Value (in Cr.)
May-25	673	25,14,297.01
Apr-25	668	23,94,925.87
Mar-25	661	24,77,221.61
Feb-25	653	21,96,481.69
Jan-25	647	23,48,037.12

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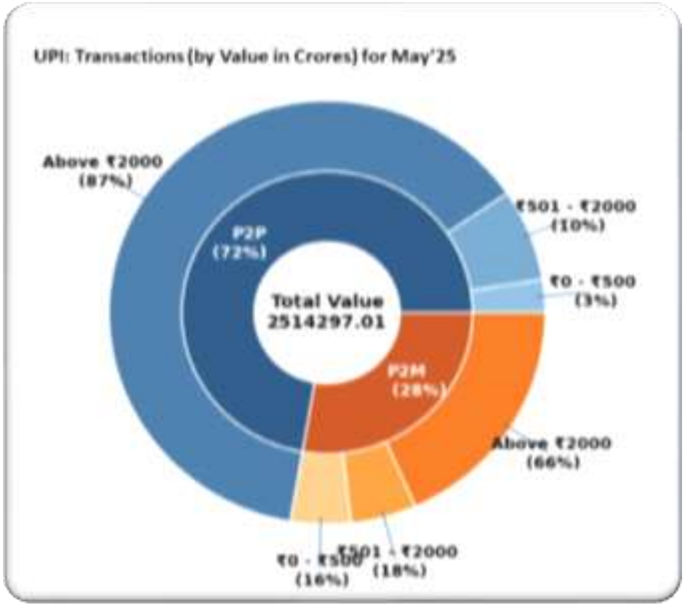
UPI P2P and P2M Transactions

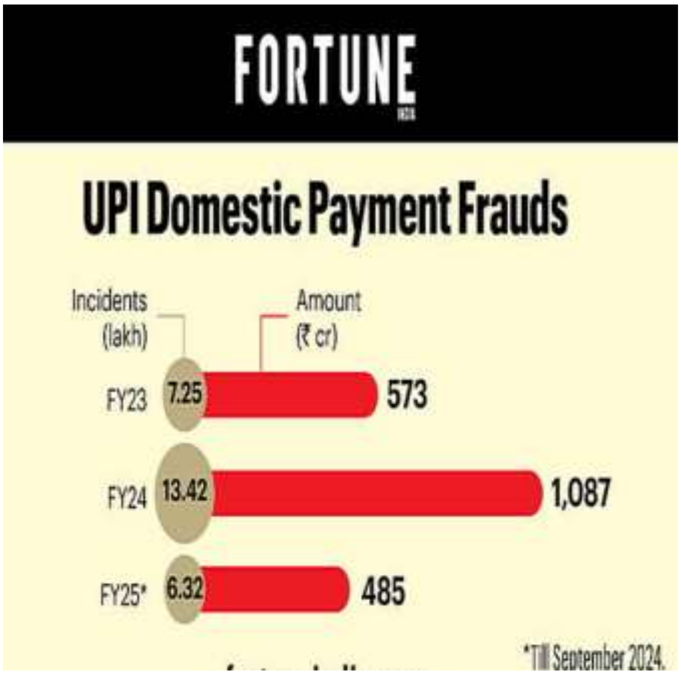
Month	Total		P2P		P2M	
	Volume (Mn)	Value (Cr)	Volume (Mn)	Value (Cr)	Volume (Mn)	Value (Cr)
May-25	18,677.46	25,14,297.01	6,823.80	18,17,672.02	11,853.66	6,96,624.99

The granular breakup of UPI shows an impressive CAGR in P2M (Person-to-Merchant) transaction volume and value, especially in the low-ticket segment (below ₹500) a clear indicator of growing adoption by consumers at the grassroots level. For instance, P2M transactions below ₹500 grew at a CAGR of 99% (volume) and 92% (value) between 2019 and 2024. UPI's impact is evident in its ability to digitize transactions and integrate low-value transaction users into the digital economy.



Source: RBI

As mobile internet and financial applications become more widespread, promoting digital financial literacy is increasingly essential. The lack of awareness about secure usage can expose users to cyber threats and financial scams. RBI statistics reveal a concerning increase in UPI-related fraud. For the financial year 2025 (up to September), approximately 6.32 lakh cases of fraud were recorded, with a total financial impact of around ₹485 crore.



Source fortuneindia

Such alarming trends underscore a paradox: while digital access has expanded, consumer safety has not kept pace. This gap highlights why financial literacy must evolve beyond basic banking awareness to include:

- Digital payment literacy
- Cyber hygiene
- Fraud prevention skills
- Understanding transaction trails and dispute mechanisms

Global Perspective: A Mixed Landscape of Financial Literacy

Globally, financial literacy is a significant issue, with only approximately one-third of adults classified as financially literate, per the S&P Global FinLit Survey. This means over 3.5 billion adults lack the basic knowledge to navigate financial systems effectively, limiting their ability to achieve financial

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security. In the United States, approximately 57% of adults demonstrate financial proficiency, but a concerning decline in risk comprehension down to 35% by 2023signals gaps in understanding complex financial concepts like investment risks. In the European Union, around 25% of adults exhibit low literacy levels, hindering their ability to engage with financial products confidently. However, countries like Finland, Singapore, and Denmark stand out as top performers. Finland's 15-year-olds top the OECD's financial literacy rankings, demonstrating the effectiveness of targeted education. Denmark with 71% adult financial literacy rate underscores the effectiveness of sturdy education strategies.

These trends underscore the need for financial literacy to empower customers globally by bridging knowledge gaps and promoting informed decision-making.

Let us understand the strategy for achieving financial literacy to strengthen the consumers:

1. **Multi-Stakeholder Approach**: Government, schools, banks, fintechs, and NGOs collaborate
2. **Curriculum Integration**: Incorporate financial modules from early schooling
3. **Competition/financial literacy Olympiads** can be conducted
4. **Digital + Offline Mix**: Complement platforms like UPI with face-to-face mentoring, especially in rural areas.
5. **Targeted Programs**: Design modules for youth, women, informal sector workers, retirees.
6. **Gamified Learning**: Leverage interactive apps, online quizzes, board games
7. **Fraud alert systems** are integrated into UPI apps.

Opportunities and Challenges in Financial Literacy Implementation

Despite its advantages, advancing financial literacy encounters some obstacles as well. One major issue is the low baseline education levels among target populations, particularly among women and rural communities.

Illiteracy and poverty often coexist, limiting individuals' ability to engage with financial education programs. Additionally, the effectiveness of financial literacy initiatives can vary, as some studies suggest that education may not immediately translate into improved financial behavior. This paradox underscores the need for tailored, practical, and culturally relevant programs that address the specific needs of diverse populations.

Technological advancements, however, present significant opportunities for scaling *financial literacy*. The rise of mobile banking can extend financial services to under-served populations. Mobile banking has made financial services accessible to millions at low cost, but its success depends on consumers' financial literacy. Digital platforms, such as SMS-based financial literacy campaigns in Jordan, offer innovative ways to deliver education to large audiences, particularly in regions with high mobile phone penetration.

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Governments and financial institutions also play a critical role in advancing *financial literacy*. In our country initiatives for Financial Literacy and Credit Counselling Centers and the U.S. President's Advisory Council on Financial Literacy demonstrate the importance of public-private partnerships in promoting financial education.

Strategies for Effective Financial literacy Programs

To maximize the impact of *financial literacy*, programs must be designed with accessibility, relevance, and sustainability in mind. First, financial education should be tailored to the **needs of specific demographics**, such as women, youth, and rural populations, who face unique financial challenges.

For instance, programs in Morocco have focused on women's roles in household budgeting, empowering them to make informed financial decisions

Second, Financial education should **leverage technology** to reach wider audiences. **Mobile-based education campaigns**, like those in Jordan, can deliver bite-sized, actionable financial advice to consumers in remote areas.

Third, programs should **emphasize practical skills**, such as budgeting, saving, and understanding loan terms, rather than theoretical knowledge. Financial literacy should focus on enabling consumers to take action, such as opening bank accounts or purchasing insurance, to achieve tangible financial outcomes.

Finally, **collaboration** between governments, financial institutions, and NGOs is essential for scaling *Financial literacy*. Initiatives like Kenya's FEP demonstrate the power of partnerships in driving financial literacy and inclusion. By aligning efforts across sectors, *financial literacy* can become a cornerstone of economic empowerment, transforming lives and

Conclusion

Financial Literacy is a powerful tool for customer empowerment, enabling individuals in developing countries to navigate financial systems, make informed decisions, and achieve economic prosperity. By fostering financial literacy, it bridges the gap between consumers and financial institutions, promotes prudent financial behaviours, and drives economic growth. While challenges like low education levels and varying program effectiveness persist, technological innovations and collaborative initiatives offer promising solutions. As developing countries continue to integrate into global financial systems, *financial literacy* will play an increasingly vital role in empowering individuals, strengthening financial markets, and fostering sustainable development.

By equipping people with the knowledge to manage their finances, *financial literacy* paves the way from knowledge to prosperity.

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Transforming the Indian Dairy and Logistics Sector through Processed, Densified, and Packed Fodder: A Sustainable Solution to Nutrition and Environmental Challenges

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India, the largest milk producer in the world, contributes over 230 million tonnes of milk annually (NDDB, 2023). Despite this, the dairy industry faces persistent feed shortages, densification with deficits estimated at 11% for green fodder, 25% for dry fodder, and 30% for concentrates. Seasonal fluctuations, high transportation costs, and post-harvest losses further compound the challenge. Meanwhile, over 120–150 million tonnes of crop residues, particularly rice and wheat straw, are burned annually, releasing harmful greenhouse gases and particulates.

Processed, densified, and packed fodder through technologies such as baling, pelleting, and Total Mixed Ration (TMR) blocks offers a transformative approach to address these challenges. By increasing bulk density from 40–50 kg/m³ to 250–300 kg/m³, transportation and storage become far more efficient. Additionally, nutrient fortification during processing can enhance feed value, while the diversion of crop residues into the dairy supply chain directly addresses environmental concerns.

This paper explores the technological processes, supply chain benefits, economic feasibility, and environmental impacts of densified fodder in the Indian context, drawing from research studies, pilot projects, and policy frameworks. The findings indicate that with integrated processing hubs, public–private partnerships, and farmer awareness, densified fodder can significantly improve dairy productivity, optimize logistics, and reduce stubble burning, contributing to India's climate resilience goals.

Introduction

The Indian dairy industry is a cornerstone of the rural economy, engaging over 80 million farming households. With an annual milk output of over 230 million tonnes (FAO, 2023), the sector has immense economic importance. However, feed and fodder shortages remain a key bottleneck.

According to the Indian Grassland and Fodder Research Institute (IGFRI), the country faces:

- Green fodder deficit: 11%
- Dry fodder deficit: 25%
- Concentrate deficit: 30%

This shortage results in reduced milk yields, poor reproductive performance, and increased production costs. Compounding the problem is the underutilization of crop residues, especially rice and wheat straw, which are often burned—a practice contributing to air pollution and GHG emissions.

Processed, densified, and packed fodder offers a dual-benefit solution:

1. **Nutritional Security for Dairy Animals Year-Round**
   One of the major constraints in Indian dairy farming is the **seasonal variability in fodder availability**. Green fodder is abundant during the monsoon season but scarce in summer and late winter, forcing farmers to rely on poor-quality crop residues or expensive concentrates. Processed and densified fodder whether in the form of pellets, compressed

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bales, or Total Mixed Ration (TMR) blocks ensures **consistent nutrient supply** regardless of the season. Because these products can be fortified with minerals, molasses, proteins, and vitamins during processing, they provide **balanced rations** that improve milk yield, reproductive performance, and animal health. Moreover, their extended shelf life means that feed can be stored in surplus months and used during scarcity, eliminating production dips and stabilizing farmer incomes.

2. **Environmental Mitigation by Reducing Residue Burning**
India generates an estimated **500 million tonnes of crop residues annually**, of which 120–150 million tonnes mainly paddy straw is burned in states like Punjab, Haryana, and Uttar Pradesh. This practice releases vast amounts of greenhouse gases and particulate matter, contributing to air pollution episodes such as Delhi's annual smog. By redirecting these residues into **fodder densification plants**, waste material is transformed into valuable livestock feed instead of harmful emissions. This approach not only **prevents stubble burning** but also contributes to climate change mitigation by reducing CO_2-equivalent emissions, improving air quality, and lowering the public health burden from respiratory diseases. Furthermore, integrating crop residues into the feed supply chain supports a **circular economy**, where agricultural by-products are reused productively, reducing dependence on imported feed ingredients and conserving foreign exchange.

Fodder Production vs. Food Crops

In India, arable land is under constant pressure due to the need to balance food grain production and forage cultivation. Farmers often prioritize cash and food crops such as wheat, paddy, maize, and pulses over dedicated fodder crops, given their higher market value and assured procurement. This leads to restricted acreage for fodder, with less than 4% of total cultivable land devoted to organized forage production (IGFRI, 2022).

The scarcity is particularly acute in states where landholdings are small, as farmers cannot afford to dedicate large plots to non-cash crops. Consequently, the dairy industry is heavily dependent on crop residues (e.g., wheat straw, paddy straw, maize stover) to meet dry fodder requirements, often without proper processing or fortification.

Seasonal Dependence

Green fodder availability in India is highly season-dependent.

- **Monsoon Season (July–October):** Abundance of green fodder due to rain-fed cultivation of maize, sorghum, bajra, and leguminous forages.
- **Summer (March–June) & Winter (November–February):** Green fodder scarcity due to water shortages, low temperatures in northern India, and competing use of irrigated land for high-value cash crops.

This uneven distribution results in nutritional gaps for dairy animals during lean seasons, affecting milk yield and quality. Farmers in fodder-deficit months often rely on costly concentrates or low-quality residues, which increases production costs and reduces feed efficiency. Dairy animals as herbivorous ruminants, require even feeding recipes, frequent changes in fodder, crops, products etc. effect their physiological performance.

Storage Losses

Post-harvest handling of fodder is inefficient in many parts of India.

- **Losses in Quantity:** Up to 20–25% of stored fodder is lost due to spoilage, mould growth, or rodent infestation (NDDB, 2023).
- **Losses in Quality:** Nutrient degradation, especially protein and vitamins, occurs when fodder is stored loosely in open conditions without protection from moisture and pests.

These losses mean that a significant proportion of fodder produced never reaches livestock in optimal condition, further deepening the deficit and farmers has to make good this loss from costly concentrated feeds.

Why Densification is Critical

Low Bulk Density Challenges

Loose fodder, such as unprocessed straw or hay, has a bulk density of approximately 40–50 kg/m³, meaning that a large volume is required to transport even a small weight. This results in inefficient logistics:

- Trucks reach their volume capacity before reaching weight capacity.
- Transporting loose fodder long distances becomes economically unviable. (means in many cases, freight cost goes up than cosy of straw or fodder)

Density Improvement and Cost Savings

Densification processes such as baling, cubing, or pelleting compress fodder into high-density units:

- **Bales:** 120–200 kg/m³
- **Pellets:** 600–700 kg/m³
- **TMR Blocks:** ~450–500 kg/m³

This 3–4x density increase allows for:

- Reduced cost per tonne-kilometre by up to 60%, as transport loads are maximized.
- Better use of existing storage facilities, as the same space can hold 3–4 times more fodder.
- Economical handling & serving to the animal

Facilitating Inter-State Trade

Fodder densification enables economically viable long-distance transport between surplus and deficit regions:

- **Example:** Punjab and Haryana produce a surplus of paddy and wheat straw (often burned), while Kerala, Tamil Nadu, and Goa face chronic fodder shortages due to limited cultivable land.
- Densified fodder makes it feasible to transport feed from surplus to deficit zones, ensuring consistent supply to dairy farmers in feed-scarce areas.

This inter-state fodder trade not only improves dairy productivity but also contributes to environmental sustainability by utilizing residues that would otherwise be wasted or burned.

Impacts on the Dairy Industry

1. Nutritional Consistency

A major challenge in Indian dairy farming is the fluctuating nutritional quality of fodder due to seasonal variations, local availability, and inconsistent storage practices.

- **Year-round supply of balanced feed:** Densified and packed fodder, whether in the form of pellets, TMR blocks, or compressed

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bales, ensures a continuous supply of nutritionally balanced feed. Since the formulation can include both roughages and concentrates, animals receive an optimal mix of energy, protein, fiber, minerals, and vitamins throughout the year, regardless of weather conditions.

- **Preventing seasonal dips in milk yield:** Research from ICAR-NIANP indicates that milk production in India drops by 15–20% during lean fodder seasons (summer and winter) due to nutritional stress. With densified feed stored for lean months, this seasonal decline can be minimized, resulting in more stable production volumes.
- **Standardized quality:** Industrial-scale processing ensures uniform particle size, moisture content, and nutrient composition. This prevents variations that could affect digestibility, rumen health, and productivity. Consistent feed quality also reduces metabolic disorders caused by sudden dietary changes.

2. Improved Supply Chain Efficiency

Fodder in loose form has low bulk density (~40–50 kg/m³), meaning it takes up excessive transport and storage space. Densification addresses this issue directly:

- **Reduction in transport costs:** By increasing bulk density to 150–700 kg/m³ depending on the product (bales, pellets, or TMR blocks), transport loads can be maximized. For example, a 10-tonne truck that carries only 3–4 tonnes of loose fodder can carry up to 10–12 tonnes of densified fodder, cutting transportation costs per tonne by up to 50% (NDDB, 2023).
- **Space-saving in warehouses:** Densified fodder occupies only one-third of the space compared to lose straw or hay, allowing processors and cooperatives to store large volumes in smaller facilities. This is especially valuable in urban or peri-urban dairy clusters where land and warehouse rentals are expensive.
- **Facilitating exports to feed-deficit countries:** Many Gulf nations (e.g., UAE, Saudi Arabia, Oman) import densified fodder from Australia, Sudan, and the U.S. India, with its surplus crop residues, can tap into this market by exporting bales and pellets. Trials conducted in Gujarat and Rajasthan have already demonstrated that Indian paddy straw bales meet international export specifications after proper treatment and packaging.

3. Market Linkages

A robust national fodder market can transform both the supply and economics of the dairy sector:

- **Connecting surplus to deficit zones:** States like Punjab, Haryana, and Uttar Pradesh produce more crop residues than their livestock populations can consume, leading to excess straw being burned. In contrast, Kerala, Tamil Nadu, Goa, and parts of the Northeast face chronic fodder shortages due to limited land for cultivation. A National Fodder Grid similar to the national power grid can connect these regions, with densification making long-distance transport economically feasible.
- **Opportunities for FPOs:** Farmer Producer Organizations can establish fodder aggregation and processing hubs, buying residues from member farmers, processing them into densified products, and selling them to dairies in deficit regions. This creates new income streams for farmers, reduces wastage, and ensures reliable supply for buyers.

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- **Private sector and cooperative participation:** Dairy cooperatives like Amul and private players like Hatsun Agro can integrate fodder processing into their supply chains, ensuring both quality feed for suppliers and a new revenue line from selling excess feed.

- **Fodder Processing in Cooperative Feed Plants**
  Adding fodder processing to cooperative feed plants offers farmers both concentrate feed and quality processed fodder from one source, reducing feed costs and improving milk yields. This lowers milk production expenses and increases the profitability of dairy plants while strengthening rural value chains.

Logistics Transformation

1. Rural Fodder Hubs

Establishing decentralized fodder processing units near crop production clusters has multiple benefits:

- Minimizes transport of bulky, low-density raw material by processing it close to the source.
- Creates local employment in straw collection, baling, processing, and packaging.
- Reduces wastage by processing residues immediately after harvest.

2. Inter-State Supply Chains

Densified fodder enables the creation of national-level fodder trade networks:

- Surplus-producing states in the north-west (Punjab, Haryana, Uttar Pradesh) can supply processed feed to fodder-deficit regions like Kerala, Tamil Nadu, Goa, and parts of the Northeast.
- Helps replace costly feed imports with domestic residue-based feed, making dairy production more competitive.

3.Export Opportunities

The Middle East particularly UAE, Oman, and Saudi Arabia imports large volumes of baled hay and alfalfa from the USA, Australia, and Sudan to support its dairy and equine sectors.

- With proper processing, quality control, and adherence to export phytosanitary norms, India can position itself as a competitive supplier.
- Proximity to Gulf markets gives India a logistical cost advantage over competitors.

Challenges and Future Directions

- **High machinery costs:** Baling machines, choppers, and densifiers require significant capital investment. For smallholders, custom hiring centers or cooperative-owned units can make technology access affordable.
- **Awareness gap:** Many farmers are unaware of the nutritional advantages of densified feed compared to lose straw, requiring targeted training and demonstrations.
- **Quality standards:** Establishing BIS or FSSAI standards for densified fodder products will ensure market trust and consistency.

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Conclusion

Processed, densified, and packed fodder offers a transformative solution to some of the most pressing challenges in India's dairy and agricultural sectors. By converting crop residues—often left to decay or burned—into nutrient-rich, transport-friendly feed, it directly addresses fodder shortages, seasonal feed variability, and rising logistics costs. Consistent, balanced nutrition improves milk yield, enhances animal health, and stabilizes farmer incomes. The establishment of fodder aggregation and processing hubs can strengthen supply chains, link surplus-producing states with fodder-deficit regions, and open opportunities in high-demand export markets such as the Middle East, adding further economic value.

From an environmental and sustainability perspective, this model plays a critical role in reducing stubble burning, thereby cutting greenhouse gas emissions and improving air quality, particularly in northern India. It promotes a circular economy by turning agricultural waste into a valuable resource, supports carbon credit generation, and reduces dependence on imported feed ingredients. To realize its full potential, the approach requires coordinated investment in infrastructure, supportive policy frameworks, farmer training, and quality standardization. With the right mix of technology, policy, and market integration, densified fodder can become a cornerstone of India's climate-smart agriculture and rural development strategy.

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Ganoderma lucidum: A Natural Treasure for Health and Wellness

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Ganoderma, particularly Ganoderma lucidum (Reishi), is a medicinal mushroom valued in traditional Asian medicine for its polysaccharides, triterpenes and antioxidants. These compounds support immunity, reduce inflammation, inhibit cancer and offer hepatoprotective, antiviral and anti-diabetic benefits. Due to its woody, bitter nature, it is consumed as extracts, capsules, or teas rather than fresh. Modern research validates many traditional claims, making Ganoderma a key element in integrative and preventive healthcare, bridging ancient wisdom with contemporary medicine. Modern science confirms many traditional uses, giving it clinical relevance today. It is increasingly valued in integrative and preventative healthcare approaches. Ganoderma represents a bridge between ancient herbal wisdom and modern medicine.

Introduction

The ancient medicinal mushroom *Ganoderma*, also called 'Lingzhi' in China and 'Reishi' in Japan, has been prized for more than 2,000 years as a sign of longevity and good health. It is a huge, black, woody fungus that grows mostly on rotting hardwood trees including oak, elm, and maple. It has a glossy, varnished surface. The Latin word "lucidus", which describes its polished appearance, means "shiny" or "brilliant". It has a long history of promoting wellness and is traditionally used in China, Japan, and other Asian countries. The Ganodermataceae family is referred to as Mannentake or Reishi in Japan.

2. Nutritional and Functional Food Relevance

Functional meals are goods that offer health advantages beyond simple nutrition, and modern consumers are embracing them at a faster pace. Medicinal mushrooms, specifically *Ganoderma*, are becoming more well-known among them because of their wide variety of chemical compounds that support complementary and individualized health care. Although *Ganoderma* has little culinary value, it is highly prized for its medicinal qualities and is frequently used in conventional herbal medicine preparations and some specialty food items.

Component	Details
Proteins	~7–8% dry weight; contains essential amino acids.
Carbohydrates	~25–30% dry weight; includes polysaccharides like β-glucans.
Dietary Fiber	High, mainly insoluble fiber from chitin and polysaccharides.
Fat	~1–2% dry weight; contains unsaturated fatty acids (e.g., oleic acid, linoleic acid).
Triterpenoids	Key bioactive compounds (e.g., ganoderic acids) with anti-inflammatory and anti-tumor activity.
Polysaccharides	Powerful immunomodulators and antioxidants.
Sterols	Includes ergosterol, a precursor of vitamin D2.
Vitamins	Small amounts of B-complex vitamins (e.g., B2, B3).
Minerals	Rich in potassium, calcium, magnesium, phosphorus, iron, zinc, and selenium.

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Taxonomy of *Ganoderma* lucidum

Rank	Name
Kingdom	Fungi
Division	Basidiomycota
Class	Agaricomycetes
Order	Polyporales
Family	Ganodermataceae
Genus	*Ganoderma*

Ganoderma lucidum collected from forest

4. Common Species of *Ganoderma*

Several species within the *Ganoderma* genus are recognized for their medicinal and functional uses. These species vary slightly in chemical composition and therapeutic effects but generally share core health benefits.

Species	Primary Use	Habitat	Appearance	Significance
***Ganoderma lucidum* (Reishi or Lingzhi)**	Medicinal	Decaying hardwoods (especially oak)	Kidney-shaped, varnished reddish-brown cap	Immune-boosting, adaptogenic properties
***Ganoderma applanatum* (Artist's Conk)**	Art and herbal medicine	Living and dead hardwood trees	Flat, gray-brown with underside that darkens when scratched	Used for drawing, medicinal uses
Ganoderma australe	Occasional medicinal use	Decaying wood (hardwoods and softwoods)	Thick, dark brown to black	Common in woodlands
Ganoderma zonatum	Pathogen	Palms in tropical regions	Conks at the base of palm trunk	Causes *Ganoderma* butt rot in palms
Ganoderma tsugae	Medicinal	Hemlock trees	Similar to G. lucidum, adapted to cold	Used as G. lucidum substitute
Ganoderma resinaceum	Medicinal/ ecological	Hardwoods in temperate zones	Reddish-orange, resinous cap	Sometimes confused with G. lucidum
Ganoderma boninense	Pathogen	Oil palms (Southeast Asia)	Fruiting bodies at palm base	Causes basal stem rot, major crop damage

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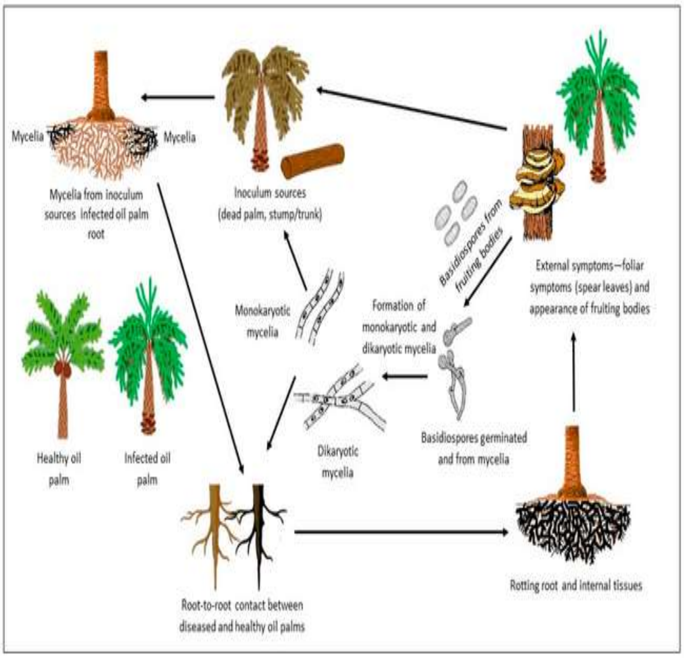
5. Life cycle of *Ganoderma* spp.

The life cycle of Ganoderma starts with the germination of spores and concludes with the development of fully developed fruiting bodies. Spores released by mature basidiocarps spread through the wind, water or anthropogenic activities. Spores germinate to produce hyphae, which enter and colonize host tissues, causing disease development, if the right moisture and substrate conditions are met. The cycle is continued when fruiting bodies grow, mature and disseminate spores under optimal conditions. Details of the life cycle can differ based on the species and the surroundings.

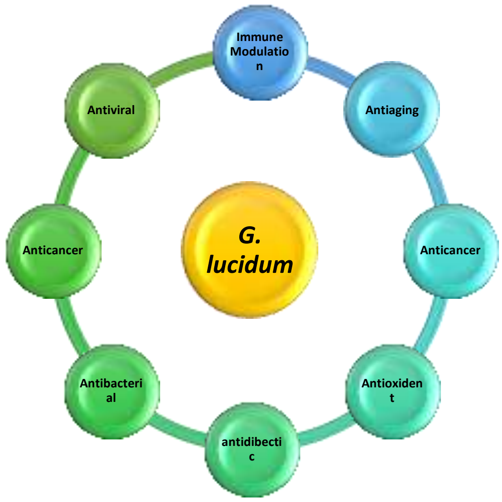


Source: Karunarathna *et al.*, 2024

6. Key Bioactive Compounds in *Ganoderma*

Compound	Therapeutic Activity
Ganoderic acids R, S	Liver protection
(1-3)-β-D-glucans	Immune stimulation and tumor inhibition
***Ganoderma* poly B**	Immune modulation and anti-cancer properties
Lucidenic acids A, D1	Bitter flavor compounds
***Ganoderma*nondiol**	Anti-HIV activity
Protein-bound polysaccharides	Liver protection
Chloroform extract	Antioxidant action

7.



Medicinal Properties of *Ganoderma lucidum*

1. **Immune Modulation** – Enhances immunity by activating macrophages, T and B lymphocytes, and cytokine production, likely converting immune precursor cells into effector cells.
2. **Anti-Aging Effects** – Rich in antioxidants and components such as GA-B, GA-C2, and GA-G, it combats age-related disorders, cancer, diabetes, atherosclerosis, and androgen-related conditions (e.g., acne, hirsutism, androgenic alopecia).
3. **Hepatoprotection** – Ganoderic acid A inhibits β-glucuronidase, reducing liver damage in animal models.
4. **Antioxidant Activity** – Natural antioxidants from *G. lucidum* rapidly enhance plasma antioxidant levels, reduce free radical formation, and improve scavenging activity, especially with chloroform-water extracts.

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5. **Antidiabetic Action –** Polysaccharides lower blood glucose without affecting insulin levels; hot water extracts reduce blood sugar within 24 hours in animal studies.
6. **Antibacterial Properties –** Exhibits activity against Gram-positive and Gram-negative bacteria; methanolic extracts inhibit *Bacillus subtilis* growth.
7. **Antiviral Capabilities –** Triterpenoids inhibit viral replication without harming healthy cells.
8. **Anticancer Potential –** Polysaccharides and triterpenes demonstrate tumor-suppressive effects; dried *G. lucidum* products are marketed globally as complementary cancer therapy agents.

8. Conclusion:

The powerful medicinal fungus *Ganoderma lucidum* contains bioactive substances that have a wide range of therapeutic effects, such as boosting the immune system, protecting organs, and preventing disease. Supported by both current research and traditional use, it is a natural alternative and functional food in integrative healthcare. Its significance on the global stage is highlighted by its economic, ecological, and medicinal worth, and further study promises new compounds and better cultivation for long-term consumption.

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Organic Farming – A Catalyst for Women's Empowerment

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Agriculture is the backbone of rural livelihoods, yet the current scenario reveals a decline in crop yields despite the heavy use of chemical inputs. The overuse of fertilizers and pesticides has degraded soil health, disrupted ecosystems, and posed serious health threats. Organic farming emerges as a sustainable alternative, restoring ecological balance, improving soil fertility, and producing healthy food. Beyond environmental benefits, organic farming has profound social implications, particularly in empowering women who have traditionally played a central role in agriculture. Their indigenous knowledge, skills in composting, seed preservation, and eco-friendly farming make them natural leaders in organic practices.

Status of Organic Farming

Globally, organic farming covers about 96.4 million hectares of farmland as of 2022, reflecting the rising commitment to sustainable agriculture. The organic products market was valued at $227 billion in 2023, projected to grow at a CAGR (Compound annual growth rate) of 10%. Australia leads with 53 million hectares, while India ranks second in organic agricultural land and first in the number of producers. India has more than 4.7 million hectares under organic cultivation, with Madhya Pradesh leading production at over nine lakh metric tons annually. Sikkim stands out as the world's first fully organic state. The Indian organic food market was valued at ₹131.41 billion in 2023 and is projected to reach ₹625.69 billion by 2028.

Rural Women's Involvement in Agriculture

Women have been at the forefront of agriculture since its inception. As per the 2021-22 Periodic Labour Force Survey (PLSF), women constitute 62.9% of India's agricultural workforce. They engage in sowing, weeding, harvesting, and post-harvest operations. Male migration has further expanded women's responsibilities, compelling them to adopt sustainable practices like organic farming. Their knowledge of natural cycles and eco-friendly practices makes them indispensable to agricultural sustainability. Notably, while men's participation in agriculture declined from 58% in 2013 to 48% in 2023, women's participation rose from 55% to 63%. Male migration significantly reshapes household dynamics, particularly in rural and agricultural communities. When men migrate for work, women are often left to assume greater responsibilities, including managing the household and making critical decisions in agricultural activities. This shift requires women to take on roles traditionally held by men, such as crop planning, land preparation, and resource allocation. While this increased involvement can enhance women's skills and confidence, it also places a substantial burden on them, as they must balance these new roles with existing domestic duties. Consequently, male migration often transforms gender roles and the socio-economic structure of rural families.

Role of Organic Farming in Rural Development

Agriculture remains the cornerstone of rural development, contributing nearly 60% of rural income in India. Organic farming enhances rural livelihoods by generating 22% higher income than conventional farming due to premium pricing and reduced input costs. It is labor-intensive, creating employment, particularly for women. Health benefits, preservation of indigenous knowledge, and opportunities in agro-tourism further contribute to rural development. The use of locally sourced organic inputs such as compost, green manure, and bio-pesticides further minimizes expenses, making organic farming more cost-effective in the long term.

Moreover, the practice often improves soil fertility and crop resilience, leading to sustainable yields over time. These factors collectively enhance the profitability and economic stability of small-scale farmers, empowering them financially while promoting environmental sustainability.

Organic farming serves as a vital pillar for boosting rural economies, providing opportunities to access international markets with high demand for quality organic produce. Products such as spices, tea, oilseeds, fruits, and vegetables find a prominent place in the global marketplace, benefiting farmers and rural entrepreneurs. India's organic farming sector, in particular, has demonstrated significant potential, with exports exceeding 400,000 metric tons in 2022. This robust trade not only generates substantial foreign exchange but also ensures better income for farmers by commanding premium prices for their products. Moreover, the international recognition of India's organic certification standards fosters trust and long-term partnerships with global buyers. By connecting rural producers to global markets, organic farming helps uplift rural communities, create employment opportunities, and promote sustainable practices. It empowers smallholder farmers, enhances their livelihoods, and positions rural India as a key player in the global organic movement.

Contribution of Organic Farming in Women's Empowerment

Organic farming has emerged as a powerful tool for empowering rural women, offering them new opportunities for income, leadership, and social recognition. For generations, women have been the keepers of seeds, soil fertility, and household food security. Their skills in compost preparation, natural pest management and intercropping are now gaining recognition as essential practices for sustainable farming. With the growing demand for organic food, these skills are no longer limited to household use but are helping women earn higher incomes by selling chemical-free produce at premium prices. This economic contribution enhances their role in family decisions and raises their social standing in the community.

Beyond financial gains, organic farming also improves the health and well-being of women and their families by reducing exposure to harmful pesticides and fertilizers. Many women's groups and cooperatives have expanded into value-added activities such as making organic pickles, herbal teas, and processed foods, which bring in additional income. Training in certification, branding, and market access further equips them to compete in larger markets. Success stories from states like Maharashtra, Uttar Pradesh, and Karnataka show that women engaged in organic farming are not only securing livelihoods but also emerging as leaders in sustainable agriculture and community resilience.

Success Stories

In Borfoidia Gohain Gaon, Jorhat, Assam, nine women formed an SHG in 2011 under the guidance of Assam Agricultural University. Through vermicomposting and sustainable practices, 70% of the village's crops transitioned to organic farming.

Another example is Momee Pegu from a Mising village in Assam, who mobilized 32 women to convert 11,000 kg of invasive water hyacinth into compost, generating ₹2.2 lakh in the first batch. These initiatives demonstrate the transformative role of women in organic farming.

Role of Cooperatives and SHGs

Cooperatives and SHGs play a pivotal role in empowering rural women through training, access to affordable inputs, and market linkages. By organizing women farmers collectively, they ensure fair pricing, reduce the role of middlemen, and enhance bargaining power. These platforms foster capacity building, improve productivity, and promote income generation.

Problems Faced by Rural Women in Organic Farming

Despite their central role, rural women face challenges like cultural and social barriers restricting decision-making, inadequate institutional support, and high costs of organic certification. These

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constraints hinder their ability to fully participate and benefit from organic farming.

Role of Extension

Extension services are vital in promoting organic farming. They improve access to innovations, provide training on climate-smart agriculture, and foster farmer networks. Gender and empowerment training helps women gain leadership roles and confidence in managing organic farming enterprises.

Conclusion

In conclusion, organic farming has emerged as a powerful catalyst for rural women empowerment, bringing about significant socio-economic changes in rural communities. By engaging in organic farming, women are not only enhancing their livelihoods but also gaining financial independence, which directly contributes to improving their status within their households and communities. The shift from conventional farming to organic practices offers women the opportunity to become leaders in sustainable agricultural practices, ensuring better health outcomes and environmental preservation for future generations. Furthermore, organic farming promotes skill development and increases women's participation in decision-making processes, thereby enhancing their leadership abilities. It creates opportunities for women to access new markets and form cooperatives, helping them to break the traditional economic barriers that often limit their growth. As women become more involved in sustainable agriculture, they are empowered to address various challenges, such as climate change and food insecurity, while fostering a deeper connection to their environment.

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Advances in Organic Techniques for Plant Disease Suppression

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Organic farming, a sustainable and eco-friendly approach to agriculture, has gained momentum globally due to increased awareness of food safety, environmental protection, and biodiversity conservation. However, managing plant diseases in organic systems poses unique challenges due to restrictions on synthetic chemical inputs. This necessitates a holistic and preventive approach that integrates ecological principles with cultural, biological, and physical methods.

1. Biological Control Agents (BCAs):

Biological control agents (BCAs) have emerged as a cornerstone of organic plant disease suppression. These beneficial microbes inhibit pathogens through competition, antibiosis, parasitism, or by inducing host resistance.

Among the most effective BCAs are:

- ✓ **Fungi:** *Trichoderma* species are particularly popular and effective against a broad range of fungal pathogens (e.g., *Fusarium*, *Pythium*, *Rhizoctonia*) and even nematodes. Other fungi like *Talaromyces* and *Coniothyrium minitans* are also gaining traction. They also stimulate root growth and enhance plant immunity.
- ✓ **Bacteria:** *Bacillus subtilis*, *Bacillus amyloliquefaciens*, and *Agrobacterium radiobacterium* are widely used. These bacteria form protective biofilms on plant surfaces and release antimicrobial compounds that suppress pathogens.
- ✓ **Viruses:** Granuloviruses and Nuclear Polyhedrosis viruses (NPVs) are being developed as biological insecticides.
- ✓ **Macrobials:** Beneficial insects, nematodes, and other larger organisms, to suppress plant pathogens indirectly by enhancing the agroecosystem's biological balance.

2. Soil Health and Microbiome Management

- ✓ **Biofumigation:** This technique involves incorporating fresh organic material (especially *Brassica* species like Indian mustard) into the soil, followed by plastic tarping. The decomposition under anaerobic conditions releases toxic volatile compounds like isothiocyanate that can inactivate soil-borne fungi, bacteria, and nematodes. This is a promising alternative to chemical fumigants like methyl bromide.
- ✓ **Anaerobic Soil Disinfestation (ASD):** Similar to biofumigation, ASD involves mixing fresh decaying organic matter into the soil, dampening it, and covering it with an airtight plastic. The resulting anaerobic breakdown creates toxic compounds that suppress a wide range of soil-borne pathogens.
- ✓ **Organic Amendments:** The application of composts, green manures, and animal manures significantly improves soil health, increases microbial diversity, and fosters the growth of beneficial microorganisms that naturally suppress diseases.

- ✓ **Minimum/No-Tillage**: These practices enhance soil organic matter, microbial activity, and beneficial microbial populations (e.g., arbuscular mycorrhiza), leading to increased soil suppressiveness against certain pathogens.

3. Cultural Practices:

- ✓ **Crop Rotation and Intercropping:** Rotating susceptible crops with non-host crops disrupts pathogen life cycles, reduces inoculum buildup, and can enhance soil suppressiveness. Intercropping can alter crop canopy, improve air circulation, and even release root exudates that deter pathogens.
- ✓ **Resistant Cultivars:** Breeding and utilising disease-resistant plant varieties remain one of the most economical and environmentally friendly methods. Advances in biotechnology are also contributing to the development of genetically enhanced resistant plants.
- ✓ **Sanitation:** Regular removal and destruction of infected plant material, proper crop residue management, and field hygiene are crucial in preventing disease spread.
- ✓ **Optimised Planting Practices:** Adjusting planting dates to avoid peak pathogen conditions, ensuring proper plant spacing for air circulation, and effective water management (e.g., avoiding overhead irrigation) can significantly reduce disease incidence.

4. Botanical Extracts and Plant-Based Biopesticides

Plants have evolved a wide range of secondary metabolites that serve as natural defences against pests and diseases. Recent advances in extraction and formulation techniques have allowed these compounds to be developed into biopesticides.

- ✓ **Neem oil (*Azadirachta indica*)**: Rich in azadirachtin, it has antifungal and antibacterial properties, effective against powdery mildew, blights, and downy mildew.
- ✓ **Garlic and ginger extracts**: These have broad-spectrum antimicrobial activity and are increasingly used in integrated organic management programs.
- ✓ **Essential oils** (e.g., thyme, clove, cinnamon): These disrupt fungal cell membranes and inhibit spore germination.

Botanical-based products offer the advantage of biodegradability, minimal environmental impact, and low risk of resistance development.

4. Plant Immunity Enhancement

- ✓ **Natural Immunity Boosters:** These products, typically made from seaweed extracts, humic and fulvic acids, amino acids, and silicon-based compounds, don't directly kill pathogens. Instead, they strengthen the plant's internal defence systems. They can activate plant defence genes, improve nutrient absorption, and increase tolerance to abiotic stresses like drought, salinity, and temperature extremes.
- ✓ **Microbial Bio-formulations for SAR (Systemic Acquired Resistance):** Beneficial bacteria such as *Bacillus subtilis* and *Pseudomonas fluorescens*, along with fungi like *Trichoderma*, can colonize the plant's roots and leaves. This process triggers the plant's systemic acquired resistance and makes the entire plant more resilient to future infections.
- ✓ **Chitosan** is a natural polysaccharide obtained from crustacean shells. It can trigger defence responses against fungal and bacterial diseases.
- ✓ **Seaweed extracts**, such as those from *Ascophyllum nodosum*, contain oligosaccharides and micronutrients. These compounds improve stress tolerance and resistance.

5. Technological Integration and Digital Tools

- **Omics Technologies**: Understanding the complex interactions within the phytomicrobiome (plant and its associated

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microorganisms) through metagenomics, metatranscriptomics, and metabolomics will pave the way for more targeted and effective biocontrol strategies.

- ✓ **Nano-enabled Immunomodulation:** Research into using nanoparticles (e.g., chitosan nanoparticles, biochar nanoparticles) to stimulate plant defence responses is emerging as a promising area for enhancing plant immunity.
- ✓ Farmers now use remote sensing, mobile apps, and AI-driven tools to detect early symptoms of disease and time the application of organic inputs more precisely.
- ✓ **Compost tea:** Liquid extracts made by soaking compost in aerated water contain a rich consortium of beneficial microbes and nutrients. They are used both as soil drenches and foliar sprays to suppress pathogens and stimulate plant defences. To increase productivity and lower labour costs, larger organic farms are also testing drone-based spraying of compost teas and biopesticides.
- ✓ **Integrated Approaches:** The most effective organic disease suppression often involves an integrated approach combining several of these techniques to create a robust and resilient agroecosystem.

Conclusion

The field of organic plant disease management is evolving rapidly, driven by scientific innovation, ecological awareness, and the growing demand for residue-free food. From microbial allies and plant-derived biopesticides to soil health strategies and digital tools, these advances represent a holistic and sustainable approach to disease suppression. As research continues to bridge traditional knowledge with modern science, organic farmers are better equipped than ever to combat diseases while preserving the integrity of the environment.

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Food Tech Revolution: Transforming the Future of Food Processing

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The global food system is at a turning point. Rising populations, increasing urbanization, changing dietary preferences and concerns over climate change are driving an urgent need for transformation in food production and processing. The 21st century consumer demands not only safe and convenient food but also products that are nutritious, environmentally sustainable and ethically produced. This shift is giving rise to the Food Tech Revolution a wave of technological innovations that are redefining how food is grown, processed, preserved and delivered.

Food technology today is not confined to preserving foods or improving taste; it is an integrated system combining biotechnology, automation, artificial intelligence (AI), sustainable engineering and digital solutions. This revolution is ensuring that food processing evolves from traditional practices to smarter, cleaner and more consumer-centric methods.

1. The Evolution of Food Processing

Traditionally, food processing was designed to increase shelf life, enhance flavour and reduce microbial risks. Methods such as drying, smoking, salting and fermentation were used for centuries to ensure survival. With industrialization, processing scaled up to meet the needs of mass populations. However, modern challenges such as malnutrition, obesity, food waste and greenhouse gas emissions demand a paradigm shift in processing strategies. The Food Tech Revolution bridges the gap between consumer expectations and technological capabilities, allowing food processing to serve multiple goals at once: safety, health, sustainability and personalization.

2. Smart and Emerging Processing Technologies

a) Non-Thermal Processing

Unlike conventional thermal methods, non-thermal technologies minimize nutrient and flavour loss:

- High-Pressure Processing (HPP): Uses hydrostatic pressure to inactivate microbes without heat, maintaining freshness and extending shelf life.
- Pulsed Electric Fields (PEF): Improves juice extraction, microbial safety and energy efficiency.
- Cold Plasma Technology: Ensures microbial decontamination with minimal impact on quality.

b) Digitalization and Artificial Intelligence

AI and Internet of Things (IoT) devices are revolutionizing quality control. Smart sensors monitor temperature, humidity and contamination in real-time, reducing human error. Machine learning algorithms predict consumer preferences, optimize supply chains and minimize processing inefficiencies.

c) 3D Food Printing

Once a futuristic concept, 3D food printing is now being applied to customize nutrition, design innovative textures and create visually appealing foods. In healthcare, it is used for preparing meals tailored to the dietary needs of patients, children and the elderly.

d) Nanotechnology

Nano-encapsulation of bioactive compounds improves stability and bioavailability of nutrients. In packaging, nanomaterials enhance shelf life by providing antimicrobial and oxygen-barrier properties.

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3. Sustainability: A Core Driver of Innovation

Sustainability is no longer an option it is a necessity. Food processing industries are among the largest contributors to waste and emissions. The Food Tech Revolution is addressing this through:

- Circular Economy Practices: Converting agricultural by-products into biofuels, animal feed and nutraceuticals.
- Energy-Efficient Equipment: Adoption of solar dryers, heat exchangers and renewable energy systems.
- Eco-Friendly Packaging: Biodegradable and edible films are replacing plastic packaging, reducing environmental impact.
- Water and Energy Recovery Systems: Reuse of process water and integration of waste-to-energy technologies.

4. Health, Nutrition and Functional Foods

Modern consumers expect foods that promote well-being. Processing innovations are now geared towards developing:

- Plant-Based Alternatives: Soy, pea protein and lab-grown meat address ethical and environmental concerns.
- Functional Foods: Enriched with probiotics, antioxidants, omega-3 fatty acids and bioactive compounds.
- Precision Fermentation: Enables production of specific proteins, enzymes and flavors with minimal resources.
- Personalized Nutrition: Using genetic and metabolic profiling, food can now be customized to individual health requirements.

5. Consumer-Centric Transformation

Digital tools are enabling consumers to make more informed choices. Examples include:

- Blockchain Technology: Ensures transparency and traceability of food supply chains.
- Nutritional Apps and Wearables: Help track calorie intake, allergies and nutrient balance.
- Smart Packaging: Uses QR codes and freshness indicators to inform consumers about product quality.

This consumer empowerment is reshaping market trends, as people seek authenticity, convenience and healthier options.

6. Challenges in the Food Tech Revolution

Despite the tremendous opportunities, challenges remain:

- High Initial Costs: Advanced equipment and digital systems require significant investment.
- Regulatory Frameworks: New technologies such as lab-grown meat and nano-packaging face strict safety regulations.
- Consumer Acceptance: Many consumers remain skeptical about genetically engineered or lab-processed foods.
- Equity and Access: Ensuring that advanced technologies reach developing nations is critical for global food security.

7. Opportunities Ahead

The Food Tech Revolution offers tremendous potential:

- Feeding the growing global population sustainably.
- Reducing food losses and waste through efficient preservation.
- Enhancing global health with functional and personalized foods.
- Building climate-resilient food systems through innovation.

Conclusion

- The Food Tech Revolution marks the beginning of a new era where technology and sustainability merge to redefine the global food system. Innovations in non-thermal processing, AI-driven automation, personalized nutrition and eco-friendly packaging are reshaping the way food is produced, processed and consumed.
- As we move forward, collaboration between scientists, engineers, policymakers and

industry leaders will be vital in overcoming challenges and ensuring equitable access to these advancements. The future of food processing lies not only in making food safer and longer-lasting but also in making it healthier, more sustainable and aligned with the needs of future generations.

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Enhancing Fertility and Wellness: Acupuncture as an Emerging Therapy in Veterinary Medicine

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Acupuncture, an ancient practice derived from Traditional Chinese Medicine (TCM), has been increasingly adopted in veterinary medicine for a variety of clinical indications. It operates through the stimulation of specific acupoints to restore physiological balance and modulate neural, hormonal, and immune functions. This article highlights the mechanisms of action of acupuncture, including activation of sensory nerve fibers, endogenous opioid release, enhanced local circulation, anti-inflammatory effects, and modulation of the hypothalamic-pituitary-adrenal axis. Across species, acupuncture is applied for pain management, musculoskeletal disorders, gastrointestinal dysfunction, and reproductive issues. Particular emphasis is placed on its role in improving fertility in large animals such as cattle and buffaloes. While generally safe and minimally invasive, the effectiveness of acupuncture depends on practitioner expertise and animal variability. Continued research into neurophysiological and molecular mechanisms is essential for further validation and broader integration into evidence-based veterinary practice.

Introduction

Acupuncture is a cornerstone of Traditional Chinese Medicine with an established history spanning more than 3,000 years. Its foundational principle is the stimulation of acupoints along meridians to regulate the flow of Qi (vital energy) and maintain physiological equilibrium. In contemporary veterinary medicine, acupuncture has transitioned from a traditional remedy to a clinically recognized complementary therapy backed by emerging scientific evidence. Anatomical studies have shown that acupoints often correspond to neurovascular structures, which may explain their physiological effects. The therapy has demonstrated measurable effects on the neurological, endocrine, and immune systems through the release of neurochemical mediators such as endorphins, serotonin, and cytokines.

Acupuncture is currently utilized to manage pain, musculoskeletal disorders, stress, inflammatory diseases, gastrointestinal dysfunction, and reproductive problems across a wide range of species. It is recognized by organizations such as the World Health Organization and the International Veterinary Acupuncture Society (IVAS), underscoring its relevance in modern animal health care. Despite this, the mechanisms of acupuncture are still being investigated, necessitating further evidence to support its efficacy and standardized application in veterinary settings.

Mechanistically, insertion of acupuncture needles activates sensory nerve fibers (Aδ and C fibers), which transmit signals to the spinal cord and central nervous system, triggering the release of endogenous opioids and neurotransmitters. Locally, acupuncture enhances blood circulation and induces anti-inflammatory responses, while centrally it modulates pain pathways and regulates the hypothalamic-pituitary-adrenal (HPA) axis, contributing to stress reduction. These neurophysiological responses also result in modulation of immune function through alterations in cytokine activity.

Clinically, acupuncture is applied across various domestic species. In horses, it is used to manage lameness, musculoskeletal pain, back pain, and navicular disease. In cattle and other ruminants, acupuncture is utilized for conditions such as mastitis, infertility, gastrointestinal disorders, and postpartum complications. In small animals like dogs and cats, it is frequently employed for osteoarthritis, intervertebral disc disease, paralysis, and chronic pain conditions such as hip dysplasia. Even in avian and exotic species, acupuncture has shown benefits in improving digestive motility, stress reduction, and postoperative recovery.

One of the most prominent and growing uses of veterinary acupuncture is in reproductive health management. It has been shown to improve anestrus, silent heat, ovarian dysfunction, and weak uterine contractions. Acupuncture can enhance uterine blood flow, normalize hormonal profiles, and stimulate follicular development, thereby improving fertility outcomes in cattle and buffaloes, especially when used as an adjunct to artificial insemination or hormonal therapy.

Acupuncture is often integrated with other treatment modalities, such as Chinese herbal medicine, electroacupuncture, moxibustion, and conventional pharmacological therapies. Electroacupuncture, which applies electrical currents through acupuncture needles, offers intensified stimulation and is particularly effective in neurological and chronic pain conditions. In some animal breeding and assisted reproductive programs, acupuncture is being explored as a supportive method to enhance success rates. Moxibustion i.e. Burning of dried herbs (usually mugwort) near acupoints to provide heat stimulation which is often combined with acupuncture to enhance blood flow and warm meridians.

When performed by qualified professionals, veterinary acupuncture is generally safe, with minimal side effects limited to mild bleeding or transient discomfort at needle insertion sites. Certification and standardization are promoted by professional bodies such as IVAS, ensuring practitioner competence. Despite its potential, some limitations persist, including variability in individual responses, differences across species, and a need for more controlled clinical trials, especially in large animal populations.

Conclusion

Acupuncture has emerged as a valuable complementary therapy in veterinary medicine due to its broad physiological effects, minimal side effects, and applicability across multiple species. Through neurochemical modulation, improved circulation, and immunomodulatory actions, acupuncture offers measurable benefits for pain management, reproductive performance, metabolic regulation, and general wellness in domestic animals. Particularly in the field of reproductive health, acupuncture has shown potential in treating anestrus, improving ovarian function, and enhancing fertility outcomes in livestock. While its efficacy can vary and further controlled studies are needed, acupuncture's safety profile and ease of integration with conventional therapeutics make it a promising tool in integrative veterinary practice. Ongoing research into its molecular and neuroendocrine mechanisms will help solidify its role and contribute to evidence-based use in animal healthcare.

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Incubating Agri-Startups & Post-Harvest Ventures

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Incubation of agri-startups and post-harvest businesses is an important bridge between farm production and demand in the market. It promotes innovation, value addition, and entrepreneurship in agriculture through ideas supported by technology, finance, and infrastructure. These businesses improve farmers' incomes, minimize post-harvest losses, and develop sustainable agri-business models. With adequate incubation, agri-entrepreneurs are able to upscale solutions for food security, rural employment, and market competitiveness.

Introduction

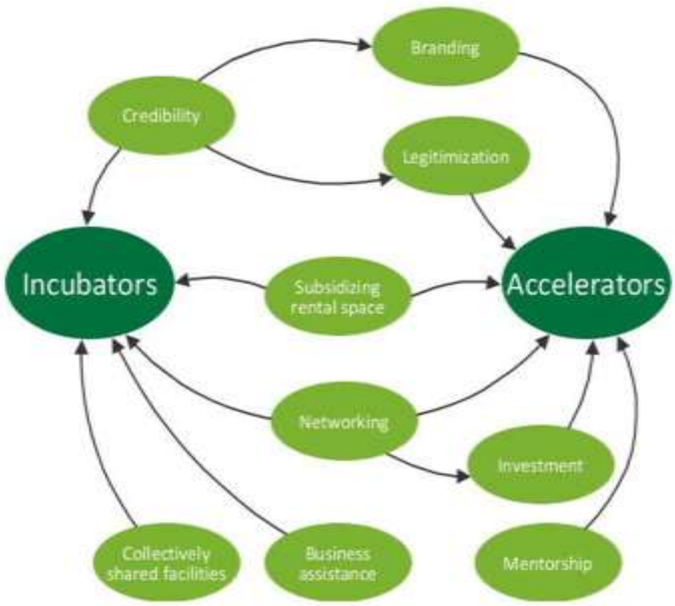
Agri-startups are now proving to be new business opportunities that aim to tackle the variety of challenges in agriculture with the incorporation of newer technologies, green business models, and innovative services. The companies are striving to offer solutions in precision farming, digital advisory platforms, mechanization of farms, climate-resilient agriculture, and market linkages. By filling the gap between conventional agriculture and newer technological interventions, agri-startups are contributing substantially to improving farm productivity, lowering risk, and guaranteeing increased profitability for farmers.

Simultaneously, post-harvest activities constitute an important part of the agri-value chain. Post-harvest activities mainly focus on processing, storage, packaging, transportation, and value addition of farm products. Post-harvest management not only reduces wastage and economic losses but enhances shelf life, quality, and marketability of produce. Post-harvest management offers possibilities for diversification into food processing, nutraceuticals, and agri-based industries with creation of additional income and employment opportunities in rural sectors.

Both agri-startups and post-harvest ventures are the pillars of agripreneurship a modern way where entrepreneurship is blended with agriculture. When combined, their contribution helps in increasing food security, improving sustainability, and inclusive growth across the agriculture industry, thus making them pillars for future modern agriculture.

3. Need for Agri-Startups and Post-Harvest Ventures

The increasing significance of agri-startups and post-harvest businesses is in their ability to revolutionize agriculture into an efficient, sustainable, and profitable industry. Post-harvest losses are still a key issue in India, with almost 20–30% lost every year due to inefficient handling, poor storage, and inefficient logistics. Apart from decreasing availability, these losses also result in considerable economic losses for farmers. Post-harvest enterprises solve this issue by providing solutions ranging from cold storage, processing facilities, packaging technology, and advanced logistics, thus increasing shelf life and returns.



Source: https://www.mdpi.com

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Agri-startups also have a crucial role in enhancing farmers' incomes through value addition and direct market access. Utilizing digital platforms, precision farming solutions, and advisory services, startups fill vital gaps in the supply of inputs, monitoring crops, and supply chain management. Farmers are able to lower production risks, lower costs of inputs, and access broader markets.

Moreover, the industry provides huge scope for generating jobs, particularly for agri-graduates, rural youth, and even professionals who are inclined towards entrepreneurial ventures. Outside economics, agri-startups promote sustainable agriculture by means of green technologies, bioproducts, renewable energy, and climate-resilient practices. In this way, their creation is crucial for food security, rural prosperity, and long-term agricultural resilience.

4. Incubation of Agri-Startups

(a) Concept of Incubation

Incubation is a formal process meant to develop new business concepts, experiment with their viability, and offer them necessary support until they become viable businesses. Incubation in agriculture is critical in filling the gap between ideas and market-driven solutions. Agri-startup incubation usually involves topics like agri-input innovations, farm mechanization and robotization, ICT applications in agriculture, biotechnology, food processing, and agri-logistics. These incubators serve as a catalyst for rural innovators, young scientists, and young entrepreneurs to convert ideas into marketable enterprises that solve important problems in agriculture and the post-harvest value chain.

Sources: https://startuptalky.com

(b) Key Components of Incubation

1. Physical Infrastructure – Incubators offer world-class facilities like laboratories, food processing units, prototyping workshops, cold storage facilities, and co-working office spaces. These allow startups to test, develop prototypes, and grow operations in a professional setup.

2. Mentorship – A robust mentorship ecosystem is one of the pillars of incubation. Established entrepreneurs, scientists, industry leaders, and policy experts offer technical, financial, and business advice. Mentorship enables startups to steer clear of mistakes, perfect their business plans, and embrace sustainable models.

3. Networking – Incubators bridge startups with investors, venture capitalists, farmer-producer organizations (FPOs), corporate partners, and market channels. Ecosystem support in the form of networking ensures that innovations are not just created but also delivered to end-users successfully.

4. Financial Support – Proximity to early-stage seed finance, venture capital, and government grants is essential for the growth of startups. Incubators often serve as a bridge between financial institutions and startups, ensuring the infusion of capital into high-potential innovations.

5. Policy Support – RKVY-RAFTAAR, Atal Innovation Mission, and NABARD schemes offer policy support, subsidies, and incubation grants. Such support enhances the entrepreneurial landscape and promotes rural youth involvement.

5. Agri-Startup Incubation Stages

Agri-startup incubation takes a systematic journey from innovative concepts to sustainable businesses. Every phase is important in developing resilience, market readiness, and long-term reach.

1. Ideation Stage:

During this phase, entrepreneurs recognize immediate agricultural issues like low productivity, high costs of inputs, post-harvest loss, or market inaccessibility. They imagine new solutions through novel technologies or business models. A rough business plan is drawn with a description of the vision, target beneficiaries (farmers, consumers, agri-businesses), and anticipated impact.

2. Validation Stage:

After the idea is developed, it is tested through proof-of-concept and pilot schemes. Startups pilot test their models with cooperatives, farmers, or agri-organisations to check for viability and feasibility. There is feedback gathered to improve the product or service, guaranteeing that it is solving actual needs. This phase establishes credibility and positions the startup for its first investor or institutional attention.

3. Early Growth Stage:

Here, startups emphasize prototype building, technology refinement, and the introduction of first market-ready products or services. Seed funding, grants, or angel investment provides crucial funding support. Startups launch small-scale sales to test revenue potential and optimize operations.

4. Scaling Stage:

With tried solutions, startups increase operations, raise production capacity, and enter wider markets. Strategic alliances with agribusiness companies, government agencies, and farmer groups reinforce outreach. Market penetration strategies, branding, and logistics infrastructure become top priorities.

5. Maturity Stage:

At maturity, the startup converts into an autonomous business with stable revenue flows, brand identity, and operational efficiency. It tends to diversify into allied businesses, attracts big-ticket investments, and supports rural development, job creation, and sustainability.

6. Incubation Centres' Role in Agriculture

Incubation centres have a catalytic role in converting innovative farming concepts into successful business opportunities. They serve as a link between the research, entrepreneurship, and farming communities by offering comprehensive support to young agripreneurs. The greatest value addition of incubation centers is that they can provide technical support. This encompassing support includes crop science knowledge, precision agriculture, mechanization, post-harvest technologies, and digital agriculture solutions. This type of counsel helps the startups create scientifically valid and market-relevant products or services.

Along with technical know-how, incubation centers enable partnerships among research institutions, universities, and startups. This connectivity is not only for tapping into sophisticated technologies and laboratories but also for collaborative innovation towards finding practical solutions to real-world agricultural issues. Incubation centers also help agripreneurs unravel the complicated legal and regulatory landscape. Advisory services on patents, intellectual property rights, licensing, and certifications enable the startups to protect their innovations and achieve market compliance requirements.

Capacity building is another important function undertaken by incubation centers. They provide entrepreneurs with management skills, financial knowledge, and market information through workshops, training, and mentoring programs. This enhances their entrepreneurial attitude and improves the capacity to overcome operational challenges.

Notably, incubation centres are also a critical connection between technology providers and farmers. Through testing new technologies with farmer producer organizations (FPOs) and cooperatives, they guarantee that innovations are tried out in actual farm conditions. This increases adoption, increases farmer incomes, and instils confidence in modern solutions.

7. Post-Harvest Ventures

(a) Importance

Post-harvest enterprises are of vital importance in minimizing farm losses, providing improved returns to farmers, and enhancing the availability of food to consumers. Agricultural products are highly perishable and, unless handled carefully, much of it is lost during transit to markets. Through the adoption of post-harvest handling techniques, perishability can be minimized and shelf life and nutritional value improved. These enterprises also assist in the development of value-added products like pickles,

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jams, dairy derivatives, and nutraceuticals, which provide new income-generating opportunities. In addition, efficient post-harvest systems enhance national food security, lower price volatility, and enhance export competitiveness by ensuring compliance with international quality standards.

(b) Key Areas

Post-harvest enterprise covers a number of interrelated areas. Warehousing and storage facilities such as cold storage, silos, and controlled atmosphere stores are necessary to maintain quality and reduce spoilage. Value addition comes from processing units through operations such as food processing, milling, oil extraction, and milk production that transform raw produce into marketable goods. Packaging technologies, particularly green and intelligent packaging, prolong product freshness and curtail wastage. Effective transportation and logistics solutions, such as refrigerated vans and blockchain-based supply chains, enable timely delivery to markets. Last but not least, market linkages—via e-commerce platforms, farmer-to-consumer models, and contract farming—connect producers with consumers, optimizing profitability.

8. Incubation Challenges for Agri-Startups and Post-Harvest Ventures

Incubating agri-startups and post-harvest ventures has a number of challenges facing growth and scalability. One of the key hindrances is poor access to venture capital and finance, which prevents young entrepreneurs from investing in technology and infrastructure. Technical knowledge and management expertise are also lacking among most rural entrepreneurs, which limits innovation and uptake. Poor infrastructure for processing, cold storage, and logistics also leads to inefficiencies. Regulations, particularly the process of getting food safety and quality certifications, slow down entry to market. Also, hard competition from mainstream brands makes it hard for startups to win consumer confidence and market share.

9. Government Policies and Support Mechanisms

The Indian Government has put in place several policies and schemes to encourage agri-startups and post-harvest businesses. RKVY–RAFTAAR facilitates incubation centers with financing, guidance, and training for agri-entrepreneurs. NABARD Agri-Business Incubation Centres extend financial support, technical expertise, and capacity development to rural startups. ICAR-NAARM and Agri-Innovate India Ltd. enable technology transfer, commercialization, and industry–research partnership. National programs like Startup India and Stand-Up India establish an enabling environment through tax incentives, loans, and eased regulations. The PM Formalization of Micro Food Processing Enterprises (PM-FME) scheme also adds strength to post-harvest businesses by enhancing processing, storage, and value addition. All these policies together promote innovation, entrepreneurship, and sustainable growth in Indian agriculture.

10. Infrastructure and Financial Support

The success of agri-startups and post-harvesting businesses is greatly dependent on strong infrastructure and sound finances. Agri-incubators set up in universities, ICAR institutions, and state departments of agriculture offer core facilities like labs, training, and business guidance. Ease of access to venture capital and angel investors is on the rise, particularly for agri-tech solutions that increase efficiency and sustainability. Conventional bank lending in the form of priority sector lending provides the availability of credit to rural entrepreneurs on conducive terms. New-age models such as crowdfunding websites allow startups to reach the customer directly and mobilize funds for farmer-centric products. Also, Private sector corporate social responsibility funds are increasingly being diverted towards the promotion of rural entrepreneurship, skilling, and generation of livelihoods. Collectively, these finance and infrastructure channels are bridging missing gaps, enabling innovators, and creating an enabling ecosystem for agricultural entrepreneurship.

11. Steps to Create an Agri-Startup / Post-Harvest Enterprise

- Identify opportunity – based on farmer needs or post-harvest gaps.
- Conduct feasibility analysis – technical, financial, and market aspects.
- Prepare business plan/project report.
- Select form of ownership – sole proprietorship, partnership, private limited.
- Register enterprise and obtain licenses (FSSAI, GST, MSME).
- Obtain finance – banks, venture funds, subsidies.
- Purchase technology/know-how.
- Develop infrastructure and operations.
- Linkage and brand marketing.
- Supervise growth and expand.

12. Future Prospects

The future for agri-startups and post-harvest businesses is very bright, spurred on by changing consumer demands and technological development. Demand for processed and packaged food will increase greatly, opening tremendous opportunities for value addition. New technologies like Artificial Intelligence (AI), Internet of Things (IoT), and blockchain will reshape agri-supply chains by improving transparency, traceability, and efficiency. The increasing demand for organic and green products presents new markets for environmentally friendly innovations. With higher-quality standards and certifications, there is the potential to expand in export markets. Additionally, climate-smart agri-startups will gain momentum, playing a crucial role in reducing carbon footprints and building resilience against climate change.

13. Conclusion

Incubating agri-startups and post-harvest enterprises is critical to upscaling Indian agriculture from subsistence to commercial, innovative, and sustainable business. Institutional backup, finance, and entrepreneurial zeal can enable agri-startups to fill gaps in productivity, post-harvest operations, and marketing links resulting in enhanced farmer livelihoods and national food security.

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Identification and Management of Plant Diseases Using Artificial Intelligence

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Traditionally, plant disease identification was carried out through visual inspection of signs and symptoms, microscopic studies, growing pathogens on culture media and biological methods such as indicator plants. Integrated management practices primarily focused on field sanitation, the use of resistant varieties, seed treatment, quarantines measures and the application of chemical treatments. But these identification methods and management strategies are time consuming, subjective, not easily scalable for large scale agricultural operations and sometime not are accurate in identifying the specific pathogen responsible for the disease. All these challenges can be overcome by the use of artificial intelligence (AI) with sensors, drones, robots and intelligent monitoring systems. This system facilitates early disease identification, outbreak prediction and optimization of treatment strategies. Additionally these AI techniques enhance crop yields, reduce the use of pesticides or fungicides and promote more efficient and sustainable agricultural practices.

AI Techniques for Crop Disease Identification:

- **Machine Learning (ML):** It involves training algorithms on data so to make predictions. The historical data of healthy and diseased plant images used in crop disease detection. ML can be used to predict the probability of a plant being diseased based on input features resulting from images, environmental conditions and previous data. Examples: Algorithms like Support Vector Machines (SVM) and Random Forests and Decision Trees, utilized in various studies to classify plant health based on features extracted from images.
- **Deep Learning (DL)**: It employs layered neural networks to analyze huge amount of data. Convolutional Neural Networks (CNNs) designed for image processing is widely used due to their efficiency in recognizing patterns in visual data. It identifies important features like leaf texture, leaf color and leaf shape, leading to more accurate disease classification. Examples: CNNs models like GoogleNet and VGG-16 used in rice and tomato diseases detection with more than 90% accuracy.
- **Computer Vision (CV):** Before analyzing images with ML and DL models, image quality also is improved by different techniques like histogram equalization, contrast adjustment and noise reduction. CV algorithms can localize infected part of the plant, enabling targeted intervention.

Advantages of AI in Plant Pathology: Artificial intelligence (AI) is transforming the field of plant pathology in numerous ways, providing modern solutions for disease detection, management and prevention. Some of the advantages of AI in plant pathology are:

- **Early disease detection:** AI can examine plant images to identify symptoms of diseases at the very early stage that allow for timely intervention before the spread of the disease occurs.
- **Improved diagnostic accuracy:** Machine learning algorithms can be trained on large datasets of plant diseases, increasing the precision of diagnosis as compared to the traditional methods and reducing human error.

- **Real-time monitoring:** AI systems can continuously monitor crops using sensors, drones, or satellite imagery, providing real-time data on plant health and enabling quick responses to emerging threats.
- **Predictive analytics:** AI can analyze environmental data and historical disease patterns to predict outbreaks of specific diseases, helping farmers to take proactive measures to protect their crops.
- **Decision support Systems:** By integrating various data sources, AI can analyze complex information to generate actionable insights and timely recommendations for disease management, improving decision-making processes.
- **Resource optimization:** AI can help in optimizing the use of resources like water, fertilizers, and pesticides by recommending targeted applications based on disease predictions, thereby minimizing waste and environmental impact.
- **Automated solutions:** Automation of monitoring and diagnostic processes using AI reduces labor costs and increases efficiency, allowing agricultural workers to focus on other critical tasks.
- **Enhancing research:** AI tools can assist researchers in discovering new disease resistance genes or understanding the complex interactions between pathogens and plants that hasten advancements in plant breeding.
- **Integration with precision agriculture:** AI with other precision agriculture technologies can enhance overall farming practices, leading to better crop management and yield prediction.

Challenges in AI for Plant Pathology:

- **Data quality and availability:** these technologies rely on high-quality, labeled datasets which are often scarce, incomplete and region-specific. The labeling process demands expert knowledge, making it time-consuming and expensive. Additionally environmental variations (seasonal changes, climate differences) complicate the creation of universally applicable datasets.
- **Scalability issues:** Many AI models are customized for specific crops or diseases, limiting their effectiveness in other contexts. Variability in soil types, farming practices and weather conditions complicates the function of AI models in other regions. Significant resources needed to adapt models to local conditions may not be feasible.
- **Integration into farming practices:** Existing AI tools often lack user-friendly interfaces, making adoption difficult for farmers with inadequate technical skills. Effective deployment requires training programs to educate farmers about technology and its benefits.
- **Ethical and economic concerns:** High costs of AI-powered tools may exclude small-scale farmers, creating disparities in access. Potential for exacalcate inequalities between large agribusinesses and individual farmers. Ethical considerations regarding data ownership and fair distribution of AI benefits must be addressed.

Future Prospects and Innovations: Future of AI in plant disease management aims to create smarter, faster and more sustainable solutions that empower farmers, improve crop health and ensure food security. Continuous advancements in machine learning algorithms, sensor technology and data integration will play critical roles in achieving these goals.

Conclusion: The integration of AI into plant disease management significantly enhances detection and diagnosis and also empowers proactive strategies to manage and mitigate disease risks effectively. As research continues to advance, the potential for AI to optimize agricultural practices and contribute to food security becomes increasingly promising.

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ICT-Based Solutions for Farmers: Mobile Apps and Digital Platforms

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Information and Communication Technology (ICT) is revolutionizing Indian agriculture through a paradigm shift from conventional, experience-based decision-making to data-based, market-linked, and sustainable agriculture. With increased internet penetration and smartphone use in rural India, farmers are increasingly connecting to mobile apps, digital platforms, and web services that give them real-time data on weather, soil health, management of pests and diseases, and prices. ICT applications like eNAM, mKisan, DeHaat, and Agmarknet are transforming crop advisories, digital extension services, and market linkages so that farmers can maximize the utilization of resources, minimize expenses, and improve profitability. These technologies also empower farmers by providing knowledge in local languages, direct farmer-consumer relationships, and access to financial inclusion services like subsidies, insurance, and direct benefit transfers. Besides the advantages, there exist pitfalls like inadequate rural internet penetration, digital illiteracy, language limitations, and data privacy. Future horizons involve coupling with Artificial Intelligence (AI), Internet of Things (IoT), and big data to facilitate predictive analytics, vernacular and voice-enabled app development, expanding digital financial services, and robust public-private partnerships. In all, ICT has tremendous potential to enhance productivity, profitability, and resilience, but inclusive, farmer-led approaches are needed to fill the digital divide and balance benefits for small and marginal farmers.

Introduction

Information and Communication Technology (ICT) has emerged as a revolutionary force in agriculture. Historically, farmers based their decision-making on experience, localized knowledge, and word-of-mouth concerning crop production, input utilization, and marketing. Nevertheless, with the quick evolution of digital technologies and the expansion of smartphone and internet penetration in rural regions, farmers are now exposed to a broad array of new and innovative tools and services.

Mobile apps, digital platforms, and web services are giving farmers access to real-time weather forecasts, soil health status, pest and disease management advice, and market price information. Such solutions help farmers make informed decisions, cut risks, and maximize the utilization of resources like water, fertilizers, and pesticides. Additionally, ICT tools are enabling direct farmer-consumer linkages and removing middlemen, thereby enhancing farm revenue.

In addition to productivity and profitability, ICT-based solutions are also advancing sustainability by encouraging precision farming, resource conservation, and climate-smart agriculture. They enable small and marginal farmers by increasing access to expert advice, promoting community involvement, and making resilience to climate change and market shocks more achievable.

Key ICT-Based Solutions

ICT-based solutions are revolutionizing Indian agriculture by providing farmers with easy-to-use tools for making decisions, market access, and timely advisories. The solutions can be bifurcated into mobile applications and digital platforms.

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1. Mobile Apps for Farmers

Weather Forecast Apps

Offer timely alerts regarding rainfall, temperature, wind speed, and extreme weather conditions, allowing farmers to schedule sowing, irrigation, and harvesting activities efficiently.

- ✓ **Examples:** IMD Weather App, Skymet Weather.

Crop Advisory Apps

Provide crop-wise advice on sowing time, seed types, time of fertilization, irrigation scheduling, pest and disease management, and post-harvesting.

- ✓ Examples: Kisan Suvidha, IFFCO Kisan, FarmBee.

Soil Health Apps

Help farmers decode the results of soil tests and advise them on balanced nutrient management, efficient use of fertilizers, and soil conservation activities.

- ✓ Examples: mKisan, Soil Health Card App.

Market Price Apps

Provide real-time mandi prices, commodity trends, and buyer contacts. Direct farmer-to-consumer or farmer-to-retailer linkages are also provided by some apps, enhancing bargaining power and profitability.

- ✓ Examples: Agmarknet, eNAM mobile app, Reliance Jio Krishi.

2. Digital Platforms

eNAM (National Agriculture Market)

A pan-India electronic trading platform interlinking over 1,000 mandis, with transparent price discovery, online bidding, and payment facilities for farmers.

Digital Extension Portals

Online knowledge centers and mobile-enabled portals disseminating advisories in local languages on crops, livestock, fisheries, and allied sectors. They also serve as virtual extension agents connecting farmers with experts.

- ✓ Examples: mKisan Portal, Krishi Vigyan Kendra Apps, MANAGE Agri-Education Portal.

Agri-Tech Startup Platforms

New-age digital ecosystems developed by startups that bring input supply, credit availability, agronomic advisory, and market connectivity on a single platform.

- ✓ Examples: DeHaat, AgroStar, Ninjacart, Gramophone.

Government Portals

Online platforms and programs that promote financial inclusion and access to subsidies, insurance, and welfare schemes through direct benefit transfer.

- ✓ Examples: PM-Kisan Portal, Pradhan Mantri Fasal Bima Yojana (PMFBY) portal, Farmer Registration Systems.

Advantages to Farmers

Informed Decision-Making

Information on prevailing weather, soil health, and pest infestation in real time allows farmers to respond quickly, minimizing risks and losses.

Reduction of Costs

ICT applications facilitate precision agriculture through the use of optimal amounts of seed, fertilizer, water, and pesticides, leading to the reduction of input costs and enhancing efficiency.

Market Linkages

Digital marketplaces and price discovery apps bring transparency, enabling farmers to get better prices for their produce and minimizing reliance on middlemen.

Knowledge Empowerment

Farmers become aware of localized, crop-specific advisories in several languages, making it inclusive and improving their technical expertise.

Financial Inclusion

Mobile banking, e-wallets, and digital crop insurance schemes enable farmers to receive direct benefit transfers (DBT), subsidies, and compensation securely and in time.

Challenges

Limited Internet Access

Most rural villages have poor internet and mobile connectivity, limiting farmers' access to the full range of ICT services.

Digital Illiteracy

Small and marginal farmers, particularly older people, are reluctant to use smartphones and apps due to lack of skills, hence limiting adoption.

Language Barriers

- ✓ Most apps come in English or Hindi only, leaving out farmers who prefer local dialects.
- ✓ Data Privacy and Trust Issues
- ✓ Misuse concerns of personal and farm information decrease farmers' participation in some digital platforms.

Future Outlook

AI, IoT, and Big Data Convergence

Predictive analytics for weather, pest infestation, and yield prediction will be made possible through advanced technologies, which will make farming more productive and resilient.

Vernacular-Based Apps

More apps designed in local languages and voice-enabled features will make ICT farmer-friendly.

Digital Financial Services Expansion

Increased coverage of mobile banking, crop insurance, and credit access via digital means will improve farmers' financial stability.

Public-Private Partnerships (PPP)

Government agency-private firm-agri-tech start-up collaboration will drive digital use and facilitate scalability of ICT applications.

Conclusion

Mobile applications and digital platforms based on ICT are transforming Indian agriculture by changing traditional farming methods towards a more informed, market-oriented, and sustainable mode. Not only do these innovations raise productivity and profitability, but they also increase resilience to climate variability, market changes, and resource shortages.

Still, the real potential of ICT to transform agriculture can be achieved only with increased awareness, enhanced digital infrastructure, and ongoing farmer training. Closing the digital divide with inclusive, vernacular-friendly, and farmer-oriented solutions will ensure that small and marginal farmers benefit equally from these technologies.

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WhatsApp Groups for Local Farmer Knowledge Exchange

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WhatsApp groups are a powerful platform for the exchange of local farmer knowledge, facilitating real-time sharing of information on crop management, pest control, weather warnings, and market prices. The groups enhance peer-to-peer learning, reinforce community networking, and offer low-cost, accessible extension services. On their part, despite the challenges of misinformation and the digital divide, case studies have shown enhanced decision-making and productivity. With good moderation and support from institutions, WhatsApp groups can be a key driver of sustainable and inclusive agricultural development.

Introduction

With the emergence of the digital age, internet connectivity and smartphones have transformed the way information is shared. Of these numerous platforms, WhatsApp has proven to be a strong vehicle for farmer-to-farmer communication and the exchange of knowledge. It facilitates rapid, affordable, and real-time dissemination of agricultural data, forging virtual communities that reinforce local extension systems. Farmers formerly used extension agents, cooperatives, and local markets to gain information. Yet, with WhatsApp groups, farmers now directly interact with peers, professionals, and institutions. This participatory approach empowers farmers to learn, adopt, and implement new practices for sustainable agriculture.

3. WhatsApp Farmer Group Objectives

The principal objectives are:

- Enabling local knowledge sharing on crop cultivation, pest control, and soil health.
- Enabling a platform for market price alerts and real-time advice.
- Establishing peer-to-peer learning networks among the farming community.
- Facilitating speedy spreading of government schemes, weather forecasts, and innovations.
- Minimizing reliance on physical meetings and printed extension materials.

4. Structure and Working of WhatsApp Farmer Groups

WhatsApp farmer groups represent organized virtual groups meant to link various stakeholders in agriculture for successful knowledge sharing and problem solving. Membership is normally comprised of farmers, extension officers, agricultural experts, local buyers, and representatives of agri-startups or cooperatives. This representation guarantees that farmers are exposed not only to peer-to-peer experiences but also scientific and market-focused knowledge.

The management of such groups is typically handled by a specific group admin, who can be a progressive farmer, extension officer, or an NGO representative. The admin helps facilitate discipline, new member approval, and keeping the discussions on topic and constructive.

Sharing content among these groups is done in a variety of formats including text messages, audio recordings, short videos, infographics, and documents. The multimedia format assists in breaking down technical information into a more readable form for farmers of different levels of literacy.

The interaction style tends to be informal and interactive, with farmers presenting their questions on field issues and receiving several suggestions from peers, specialists, or extension agents. This facilitates participatory decision-making and co-creation of knowledge.

The key themes of knowledge addressed include farm management practices for crops, pest and disease control, availability of inputs and machinery, weather forecasts and warnings, and market connections and price movements. These conversations not only address short-term farm-level challenges but also enable farmers to cope with evolving climatic and market conditions.

5. Benefits of WhatsApp Groups for Farmers

WhatsApp groups have emerged as a novel means of enhancing agricultural extension and farmer-to-farmer connectivity. Their advantages are multi-fold, having direct implications on farmers' decision-making and livelihoods.

a. Instant Information Sharing

Perhaps the most significant advantage is the availability of information in real-time. Farmers grappling with pressing issues like acute pest infestations, disease attacks, or nutrient deficiencies can ask questions and have answers provided to them instantly. This real-time exchange reduces crop losses and facilitates timely decision-making.

Source: https://whatagrouplinks.com/agriculture

b. Low-Cost Communication

As compared to physical extension service meetings, travel, and printed materials, WhatsApp uses only an internet connection. This is thus a very cost-saving method of communication for both extension workers and farmers, as it alleviates the time and resource burden.

c. Inclusive Learning

WhatsApp groups are by their nature inclusive, as even smallholder farmers in areas far from physical extension services can become members. Through the utilization of local languages and simple modes of communication, groups facilitate greater participation across economic and social classes.

d. Capacity Building

Exposure to new practices through peer experiences generates confidence among farmers. If one farmer experiences a successful method or application of new technology, others are encouraged to apply similar methods. Peer learning facilitates learning-by-seeing, which is easier than formal training.

e. Strengthening Community Bonding

These groups transcend knowledge sharing by building robust community bonds. Farmers forge trust among each other, exchange resources, and help each other in times of need, building collective resilience.

6. Issues in WhatsApp Farmer Groups

While WhatsApp groups have demonstrated great potential in strengthening farmer-to-farmer knowledge sharing, they also pose a series of issues that must be overcome for optimal performance.

Digital Divide

One of the most significant problems is unequal access to digital assets. Not every farmer possesses smartphones or internet access. This leaves a gap, where only part of the farming community gains from such groups, excluding resource-poor or marginalized farmers.

Information Overload

The large amount of messages sent in active groups can usually prove to be too much. Important information and unnecessary chats can get confused, and the platform becomes less effective, causing frustration to farmers.

As anybody can post content, there's always a chance of misleading or unverified information flowing in. Misguided advice on pesticide application, crop protection, or market price can cause economic loss or even pose health risks to farmers.

Language Barriers

Technical information given in English or technical jargon is not easy for farmers to comprehend. In order to be effective, messages have to be uncomplicated and communicated in local languages to facilitate better understanding and acceptance.

Limited Expert Presence

Most groups suffer from inadequate permanent involvement of trained agricultural specialists. Consequently, interventions are predominantly peer-to-peer, which, although useful, also raises the likelihood of dissemination of misinformation or half-knowledge.

7. Case Studies / Examples

The effect of WhatsApp farmer groups can also be better realized through real-life scenarios from various parts of India, where they have been used effectively for knowledge management and problem resolution.

Case 1: Cotton Farmers in Maharashtra

Cotton growers in Vidarbha experienced recurring losses from the Pink Bollworm infestation. WhatsApp groups were formed to exchange real-time alerts about pests and encourage Integrated Pest Management (IPM) techniques. Scientists and extension workers made announcements on proper pesticide use, trap placement, and on-time spraying regimes. Farmers achieved 20–25% less crop loss due to these initiatives, proving the utility of digital collaboration in managing pests.

Case 2: Paddy Farmers in Eastern Uttar Pradesh

A number of villages across Eastern Uttar Pradesh's districts employed WhatsApp groups to share transplanting methods, the best ways of irrigation, and weather forecasts in real time. Information regarding government procurement centers as well as Minimum Support Price (MSP) policy was also shared using the groups. It helped make farmers more informed, allowing them to sell their crops at official MSPs and forego exploitation by middlemen, thus increasing farm returns and transparency.

Case 3: Dairy Farmers in Gujarat

Dairy farming WhatsApp groups in Gujarat served as key platforms for the exchange of feed formulation advice, veterinary advice, and cooperative information. Farmers were able to easily get solutions for animal health problems and reminders regarding milk collection schedules. This helped deliver enhanced livestock productivity, quality milk, and profitability for dairy farmers.

8. Role of Institutions and Extension Services

The success and viability of WhatsApp farmer groups are highly dependent on the participation of formal institutions and extension services, which help make information exchanged reliable, timely, and useful for farmers.

Krishi Vigyan Kendras (KVKs)

KVKs are farm frontline extension stations that are engaged in the training of farmers and in the dissemination of technology. Through official WhatsApp groups, KVKs can provide instant advisories on crop protection, nutrient management, weather information, and government schemes. This ensures that the information conveyed is credible as well as being practically applicable.

State Agricultural Universities (SAUs)

SAUs possess a robust group of subject-matter experts who can actively engage in WhatsApp groups to offer expert advice. Researchers and scientists can directly respond to farmer questions, clear myths, and facilitate the adoption of new technologies. This bridges the research institution-farmer gap.

Government Schemes

Government departments can utilize WhatsApp groups as a useful platform to disseminate information on subsidies, crop insurance, procurement policies, and new agriculture missions. Real-time updates on this forum enable farmers to avail benefits and make wise choices regarding resource utilization and marketing.

NGOs & Agri-Startups

Non-Governmental Organizations and agri-startups also play a vital role by connecting farmers with e-markets, online suppliers of inputs, and financial institutions. They frequently organize training in digital skills and management of groups, increasing the efficiency and inclusivity of farmer networks.

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9. Best Practices for Effective WhatsApp Farmer Groups

For WhatsApp farming groups to work efficiently and act as credible knowledge platforms, some best practices must be adopted. They help ensure that information is accurate, accessible, and farmer-friendly, as well as prevent misuses of the platform.

Use of Local Language

Local languages or local dialects should be used to send messages to help avoid confusion and enable better comprehension. Technical jargon should be translated in simple language so that farmers from varying levels of literacy can equally benefit.

Appoint Trained Moderators

Moderators should be trained extension officers, progressive farmers, or NGO representatives to manage groups. Moderators assist in eliminating unwanted content, keep discipline, and ensure discussions remain centered on agricultural topics.

Verified Content Sharing

Share only verified content from trusted sources such as KVKs, SAUs, government departments, or experts who are well-recognized. This reduces the chance of misinformation, especially in sensitive topics like pesticide management or disease control.

Use of Multimedia Tools

Sharing audio messages, short explanatory clips, and infographics increases clarity and makes technical information more pragmatic and easily adoptable, particularly for illiterate farmers.

Topic-Focused Groups

Crop-specific or region-specific groups ensure more relevant and contextual discussions. This avoids information overload and enables farmers to concentrate on matters immediately relating to their context.

Encouraging Feedback and Success Stories

Agriculturists must be encouraged to exchange their experiences, innovations, and success stories. It increases confidence, facilitates learning from peers, and enhances the community spi10rit.

10. Future Prospects

The function of WhatsApp farmer groups will extend with inclusion of AI, chatbots, and voice-based advisories in local languages. Interlinkages with Digital Agriculture platforms, e-NAM, and precision farming tools will position them as a fundamental component of smart agriculture ecosystems.

In the future, WhatsApp groups may evolve into digital cooperatives, enhancing farmer bargaining power, improving supply chain efficiency, and enabling climate-resilient agriculture.

11. Conclusion

WhatsApp groups are making exchange of local farmers' knowledge a participatory, quick, and low-cost affair. Though challenges still exist, their contribution to bridging the gap in information, fostering community learning, and facilitating inclusive extension services cannot be denied. With institutional backing and effective administration, WhatsApp-based farmer groups can emerge as a pillar of digital agriculture in India and the wider world.

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Precision Planting Techniques for Higher Yields

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Precision planting is a sophisticated agricultural method that guarantees seeds are planted in the correct depth, space, and population to achieve optimal germination and yield. Precision drills, GPS-guided planters, pneumatic systems, and sensor-based technologies are some of the latest tools utilized by farmers to minimize seed loss, enhance crop establishment, and make inputs more efficient. The method not only increases productivity but also encourages sustainability through minimized resource losses and environmental strain. With increasing focus on climate-smart agriculture, precision planting is a revolutionary path to realizing more yields and effective, profitable farming systems.

Introduction

Planting in contemporary agriculture is not merely about seeding the soil; it is seeding at the proper depth, spacing, and population to optimize germination, growth, and yield. Precision planting is a cutting-edge method that employs advanced machinery, sensors, GPS, and data-driven equipment to plant seeds with precision. It seeks to optimize input savings, maximize crop yields, and enhance sustainability. Metaphorical broadcasting or hand planting usually leads to unbalanced germination, competition among crops, and reduced yield. Precision planting, by contrast, minimizes field variability and provides each seed with the best possible environment to grow, thus releasing more yield potential.

3. Objectives of Precision Planting

Precision planting is meant to counteract the inefficiencies of conventional sowing techniques by providing each seed with optimal conditions for development. The main aim is to obtain uniform seed distribution as far as depth and distance between them are concerned. This reduces intra-plant competition and allows each plant to have proper access to sunlight, water, and nutrients, hence promoting even growth and increased productivity.

- One other vital goal is to maximize plant population in a manner that ensures fields have maximum resource utilization efficiency. Farmers are able to control crops by adjusting spacing and seeding rates in a manner that prevents overcrowding as well as inefficient use of land. This results in greater yield potential with more consistent crop stands.
- Precision planting also aims to reduce seed and input wastage. Good quality seeds, fertilizers, and water are expensive resources, and improper placement or irregular sowing result in huge losses. Precision technologies guarantee that inputs are applied precisely where and when they are required.
- Moreover, the method seeks to enhance germination levels and establishment of crops. Proper depth placement provides enhanced seed-soil contact and accessibility of moisture, which are essential for even and healthy emergence of seedlings.
- Through optimization of mechanization application, precision planting minimizes reliance on labor, which is becoming increasingly limited and costly in most farming areas. Not only is this time-saving, but it also reduces cost of production.
- Lastly, the general purpose is to enhance profitability and ensure sustainability in crop production systems. Through yield maximization, resource conservation, and input savings, precision planting enhances farmer revenues and protects the environment.

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Source : cropin

4. Precision Planting Techniques and Technologies

Precision planting combines advanced machinery, digital technology, and data-based technologies to improve crop establishment and optimize yields. A number of advanced techniques are gaining extensive usage:

a. Precision Seed Drills and Planters

They have adjustable seed metering mechanisms that provide equal depth and spacing. They are applied extensively in cereals, pulses, and oilseeds, helping to achieve proper seed use and improved crop stand.

b. GPS and GIS-based Planting

Global Positioning System (GPS) and Geographic Information System (GIS) technology allow tractors and planters to travel in straight lines with regular spacing. This helps avoid overlaps, prevent gaps, and achieve improved land use.

Source:editverse

c. Variable Rate Technology (VRT)

VRT-equipped planters can change seed rate and planting depth automatically based on variability in fields like soil fertility, moisture levels, and organic matter. This provides site-specific management for increased productivity.

d. Pneumatic and Vacuum Planters

These modern planters employ air pressure or vacuum suction to place one seed at a time. Double sowing and missing spots are greatly minimized, resulting in uniform crop emergence.

e. Sensor-based Planting Systems

Soil and environmental sensors measure current conditions such as soil moisture, compaction, and residue cover. Depth and placement are then adjusted by the planter, enhancing germination and stand uniformity.

f. Drone-assisted Precision Planting (Emerging)

Drones are being explored for aerial seed dropping in rice, forestry plantations, and specialty crops. Aerial seed dropping minimizes labor dependency and enables planting in challenging terrains.

5. Benefits of Precision Planting

Precision planting offers various benefits that account for increased productivity, profitability, and sustainability of agricultural systems. Its applications range from enhanced crop performance to ecological balance in the long run.

a. Increased Yields

One of the main advantages is improved yield. Even seed placement and adequate spacing minimize intra-plant competition for light, water, and nutrients. Every plant has an equal chance to grow vigorously, thus producing stronger crop stands, uniform maturity, and greater harvestable yield.

b. Input Efficiency

By putting seeds, fertilizers, and other inputs exactly where they are required, precision planting maximizes the use efficiency. Fertilizer application is coordinated with crop requirements, whereas irrigation may be oriented towards plant population density. This reduces wastage of expensive inputs, minimizes costs of production, and reduces the risk of environmental contamination.

c. Improved Germination and Crop Establishment

Even contact with soil moisture and proper planting depth provide excellent germination conditions. This results in rapid and uniform crop emergence, lessening the occurrence of patchy fields. Uniform stand also promotes effective weed control and makes crop management simpler.

d. Labor and Time Saving

Mechanized precision planters greatly decrease reliance on hand sowing, which tends to be slow, variable, and time-consuming. Scheduling of planting operations is feasible over extensive regions in a shorter time, which is particularly crucial in narrow sowing windows of species such as wheat and rice.

e. Sustainability

Effective use of resources is what leads to sustainable agriculture. Less wastage of seeds, fertilizers, and energy reduces the carbon footprint of agricultural operations. Accurate placement also reduces disturbance in the soil, hence preserving soil structure and health. In the long run, precision planting balances productivity with environmental sustainability, ensuring climate-change resilience.

6. Challenges in Adoption of Precision Planting

Despite the clear advantages of precision planting technologies, their widespread adoption faces several challenges, particularly in developing agricultural regions.

High Initial Cost: The procurement of advanced planters, GPS-guided systems, and sensor-based machinery involves heavy investment. Small and marginal farmers often find it financially unfeasible without government subsidies or cooperative models.

Technical Knowledge and Skill Gap: Precision planting machinery needs training in the operation of GPS, sensors, and calibration of metering equipment. There is a lack of awareness and restricted access to extension services preventing effective use.

Small and Fragmented Land Holdings: For those nations such as India where farm sizes tend to be below two hectares, there cannot be effective use of large precision planters. Irregularities in the field and fragmented holdings lower effectiveness even more.

Power and Infrastructure Requirement: High horsepower tractors or special machinery are often required by many sophisticated machines, to which small farmers do not have access. Also, continuous power supply and internet connectivity are needed for GPS and IoT-based systems.

Maintenance and After-Sales Support: Spare parts, trained service personnel, and repair at the right time are not easily available in rural areas. This adds to downtime and deters adoption.

Socio-economic Constraints: Farmers are usually reluctant to adopt due to risk perception, absence of short-term apparent advantages, and reliance on availability of credit.

Policy and Institutional Gaps: Imperfect access to funding options, poor promotion of custom hiring centers, and lack of farmer cooperatives further restrict extensive adoption.

6. Case Studies / Examples

Case 1: Maize in Karnataka

Karnataka farmers who adopted pneumatic precision planters for cultivating maize experienced a notable productivity improvement. Correct depth placement of the seed ensured uniform germination, minimizing intra-plant competition. This led to a 15–20% increase in yield over conventional sowing methods. Additionally, the accurate seed metering system reduced wastage, enabling the farmer to reduce input costs. This is an example of how precision planting helps to ensure not only yield increase but also economic efficiency.

Case 2: Soybean in Madhya Pradesh

In Madhya Pradesh, soybean growers started using GPS-guided planners to correct non-uniform spacing and irregular depth placement of seeds. The technology facilitated precise seed-to-seed spacing, and this translated into equal plant populations. This directly enhanced pod setting and improved seed quality, leading to increased market value. Farmers also experienced less consumption of seed material, which reduced costs while sustaining or enhancing returns. The use of GPS planters demonstrated the improvement in productivity and quality of legume crops through precision planting.

Case 3: Punjab Rice (Direct Seeded Rice – DSR)

Punjab farmers have tested precision seed drills in Direct Seeded Rice (DSR), a substitute for the conventional transplanting. Precision planting saved 25–30% of water while keeping yield levels equivalent. This transition substantially decreased labor dependency and enabled farmers to combat water scarcity issues. The technology was climate-smart, presenting both sustainability and profitability through decreased input requirements while preserving natural resources.

7. Best Practices for Precision Planting

For optimal use of precision planting, farmers need to adopt scientifically driven practices suited to local conditions. The choice of planters is the key starting point; selecting equipment matched to crop type, seed size, and soil type ensures proper placement of seed. For example, pneumatic planters are best suited to maize and soybean, while drills are effective for cereals and pulses.

Seed meter calibration prior to every sowing season is necessary to ensure accurate seed spacing and depth. Any slight misalignment could impact population and yield returns. Pre-plant soil testing gives an idea of fertility levels and allows adjusting seed rate and fertilizer application accordingly to ensure optimal utilization of nutrients and wastage.

Utilization of certified, quality seeds improves uniformity of germination and vigor of the crop. Precision planting is most effective when it is coupled with timely sowing because it synchronizes crop development with optimal climatic conditions, especially availability of moisture and temperature. Sowing delays, even with precision tools, may lower the potential yield.

Farmer training and capacity development programs are key to extensive adoption. Field schools and demonstrations introduce farmers to planter modifications, GPS-guidance systems, and troubleshooting methods. Proper maintenance of equipment and provision of spare parts further contribute to operational dependability.

Implementing integrated methods—integration of precision planting with site-specific nutrient management, mechanized irrigation, and pest monitoring—earns maximum returns in terms of yield, sustainability, and profitability.

In short, precision planting offers the best outcomes with the support of suitable machinery choice, calibration, quality seeds, soil analysis, on-time sowing, and capacity development for farmers. These practices not only provide increased output and optimal resource utilization but also ensure long-term environmental and soil sustainability.

8. Future Prospects

The future of precision planting is in the convergence of AI, robotics, and IoT-based sensors. Smart planters with real-time adjustments, drone-based sowing, and autonomous equipment will transform sowing operations. Subsidies from the government, farmer cooperatives, and custom-hiring centers will make precision planting affordable for smallholders, enabling mass adoption and increased productivity.

9.Conclusion

Precision planting methods are a revolutionary technique for contemporary agriculture, where each seed is planted in the most favorable environment for growth. Through a union of science, technology, and farmer involvement, it optimizes yields, enhances input use efficiency, and enables sustainable agriculture systems. Despite constraints, integrating superior technologies with farmer-conducive policies can turn precision planting into the keystone of future agriculture.

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Selection and Evaluation of Candidate Plus Trees for Limonia acidissima: Advancing Genetic Improvement and Agroforestry Sustainability

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India's diverse agro-climatic zones support the cultivation of a variety of fruit crops, including both major and minor species such as wood apple (*Limonia acidissima*), phalsa (*Grewia subinaequalis*), and jambhul (*Syzygium cumini*). Among these, *Limonia acidissima*, a multipurpose tree species native to South and Southeast Asia, plays a critical role in agroforestry systems. Valued for its edible fruits, medicinal properties, and durable wood, *L. acidissima* is highly adaptable to dry and semi-arid conditions, contributing to its ecological and economic significance. The genetic improvement of such species relies on the identification of superior individuals, or Candidate Plus Trees (CPTs), which serve as the foundation for breeding and conservation programs. CPT selection focuses on phenotypically superior traits such as growth rate, stem form, fruit yield and resilience to abiotic stresses. In the case of

L. acidissima, CPTs are identified based on specific criteria, including girth at breast height, bole length, crown architecture and fruit quality. These selected trees are valuable for clonal propagation, seed orchard establishment and the long-term conservation of genetic resources. Recent studies have shown the potential of CPTs to enhance productivity, improve wood quality and increase resistance to diseases, making them crucial for sustainable agroforestry. This systematic approach to CPT selection provides the necessary genetic material for improving the species' ecological resilience, economic value and overall productivity. Accurate documentation, including geo-coordinates and tree passport data, ensures the sustainable utilization of these elite genotypes in future breeding and conservation efforts.

Introduction

India possesses diverse agro climatic conditions that facilitate the cultivation of a wide spectrum of fruit crops, including tropical, subtropical and temperate species. In addition to major fruits, several minor fruit crops such as wood apple (*Limonia acidissima* L.), phalsa (Grewia subinaequalis), jambhul (Syzygium cumini) and karonda (Carissa carandas) are cultivated in regions with favorable environments (Kerka et al., 2020). L. *acidissima*, the sole species of its genus in the family Rutaceae, is a slow-growing, deciduous tree native to the dry plains of India and Sri Lanka, with distribution extending across South and Southeast Asia (Morton, 1987; Chowdhury et al., 2024). The species is multipurpose in nature, valued for its edible fruits, medicinal applications and durable wood. Its fruits are rich in vitamins, antioxidants and phytochemicals, while the hard, yellow-grey wood is traditionally utilized in construction and agricultural implements (Khare, 2007; Orwa et al., 2009). Due to its adaptability to dry and semi-arid regions, L. acidissima is of considerable ecological and economic importance in agroforestry systems and rural subsistence strategies. Genetic improvement of multipurpose tree species such as L. acidissima necessitates the identification of phenotypically superior trees to form base populations for further breeding and conservation. Candidate Plus Tree (CPT) selection is a fundamental approach in forest tree improvement programs, where individuals are identified based on superiority in growth rate, stem form, fruit yield and health status

(Zobel & Talbert, 1984; FAO, 2014). Selected CPTs serve as primary sources of quality germplasm for clonal propagation, seed orchard establishment and long-term conservation (Nicodemus et al., 2009). Recent research in India has employed CPT selection for L. acidissima, with field surveys identifying superior trees across natural populations using selection criteria such as girth at breast height, bole length, crown architecture, fruit yield and seed attributes The systematic documentation of these CPTs, supported by geo- coordinates and tree passport data, provides a scientific basis for sustainable utilization, genetic improvement, and conservation of this underutilized but economically significant species.

Selection Criteria for Candidate Plus Trees: Key Characteristics and Evaluation Factors Role of Candidate Plus Trees (CPTs) in Tree Improvement Programs

A Candidate Plus Tree (CPT) is defined as a phenotypically superior individual identified within natural populations or plantations, selected for desirable attributes such as enhanced growth rate, straight clear bole, higher yield, disease resistance and superior fruit or seed quality, when compared with surrounding trees of the same species and age (Zobel & Talbert, 1984). The identification of CPTs constitutes the initial and most fundamental step in tree improvement programs, as they represent the best available genetic resources in natural forests or on-farm stands. Propagules in the form of seeds, scions, or cuttings obtained from CPTs are utilized for the establishment of clonal seed orchards, seed production areas, and breeding populations. Although CPTs have not undergone genetic evaluation through provenance or progeny testing, they are regarded as elite candidates for advanced selection, clonal propagation, and further genetic improvement.

Growth Performance

Candidate Plus Trees (CPTs) must demonstrate exceptional growth compared to the general population, with significantly higher values for height, girth at breast height (GBH) and overall tree volume. These traits should exceed the average performance of surrounding trees, indicating superior genetic potential for growth (Zobel & Talbert, 1984; Nicodemus et al., 2009).

Stem Structure and Bole Quality

CPTs should possess a straight, cylindrical stem with minimal tapering and no significant forking up to a considerable height. These structural features are crucial for ensuring the tree's stability, mechanical strength, and suitability for timber production (Orwa et al., 2009).

Crown Development and Architecture

A well-formed, symmetrical crown is essential for CPTs, with balanced branching that promotes optimal light interception and efficient photosynthesis. The tree should have sufficient spacing between branches to avoid overcrowding, which helps ensure healthy crown development and good tree structure (Nicodemus et al., 2009).

Reproductive Capacity

CPTs must consistently produce high-quality flowers and fruits. The trees should exhibit regular and abundant flowering with large fruits that possess good pulp quality and viable seeds, essential for successful propagation and genetic improvement (Chowdhury et al., 2024; Khare, 2007).

Health, Vigour, and Stress Tolerance

Healthy CPTs should be free from pests, diseases, and mechanical damage. Additionally, these trees should show resilience to abiotic stresses, such as drought and temperature fluctuations, ensuring their ability to thrive under varying environmental conditions (Orwa et al., 2009).

Comparative Superiority and Evaluation

Each CPT should be assessed in comparison to 10–15 neighboring trees of similar age to confirm that its superior traits are genetically determined, rather than influenced by site-specific factors. This comparative evaluation ensures that only the best genetic material is selected for further breeding (Zobel & Talbert, 1984; FAO, 2014).

Record Keeping and Tree Marking

Accurate documentation is essential for tracking CPTs. Geo-coordinates, photographs, and passport data should be recorded for each selected tree. These trees should also be clearly marked to facilitate their inclusion in germplasm collections and ensure they are accessible for future breeding and propagation efforts (Forest Department of Odisha, 2024).

Benefits of Selecting Candidate Plus Trees (CPTs)

Genetic Improvement and Breeding Potential

Candidate Plus Trees (CPTs) are selected based on their superior phenotypic traits, making them a valuable source of high-quality genetic material. By choosing CPTs, breeders can establish a solid foundation for genetic improvement programs aimed at enhancing tree productivity, resilience, and overall performance (Zobel & Talbert, 1984).

High-Quality Seed Source for Enhanced Propagation

CPTs serve as an excellent source of seeds, as they are expected to produce offspring with superior germination rates, enhanced vigor, and greater adaptability. These seeds, derived from genetically superior trees, contribute to the establishment of stronger and more resilient tree populations (FAO, 2014).

Clonal Propagation and Establishment of Seed Orchards

CPTs are integral to the establishment of clonal seed orchards, where high-quality genetic material is mass-multiplied to produce a consistent supply of genetically superior trees for large-scale planting. This approach ensures the rapid multiplication and distribution of elite traits (Nicodemus et al., 2009).

Conservation of Genetic Resources

Selecting and preserving CPTs is crucial for the conservation of valuable genetic resources, particularly in underutilized species that may otherwise face genetic erosion. By identifying and protecting these superior genotypes, we safeguard the genetic diversity needed for sustainable breeding and long-term tree improvement efforts.

Enhanced Productivity and Economic Value

Choosing CPTs helps drive improvements in key traits such as fruit yield, wood quality, tree form, and pest/disease resistance. This not only enhances the economic potential of tree-based industries but also contributes to ecological sustainability by promoting healthier, more productive trees with better adaptability to changing environments (Orwa et al., 2009).

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Building Resilience through Community-Based Farming Groups

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Agricultural resilience needs to be built collectively, particularly for smallholders who are exposed to climate variability, economic shocks, and resource limitations. Community-Based Farming Groups (CBFGs) empower farmers by promoting cooperation, sharing resources, and propagating climate-smart agriculture. CBFGs build adaptive capacity through joint marketing, access to finance, knowledge transfer, and social protection. Through reinforced economic, social, and environmental resilience, CBFGs minimize vulnerabilities and enhance livelihoods. Strong policy support, capacity development, and infrastructure development are essential in order to maintain these groups as drivers of resilient agricultural communities.

Introduction

Developing-country agriculture is increasingly threatened by climate variability, soil erosion, water scarcity, pest infestation, and volatile market conditions. These stresses disproportionately impact smallholder farmers, who constitute the majority of food producers but frequently remain deprived of access to innovative technology, institutional credit, and assured market information. Their exposure is also compounded by fragmented holdings and poor bargaining capacities. In turn, Community-Based Farming Groups (CBFGs) have been seen as a potent collective approach to developing resilience. Through shared resources, knowledge exchange, and sustainable agricultural management, these groups facilitate farmers in risk avoidance and increased adaptive capacity. In addition to productivity, CBFGs cultivate social solidarity, collective decision-making, and economic empowerment. The overall philosophy is straightforward but strong: "Together we are stronger"—converting vulnerabilities to collective strength for sustainable agricultural futures.

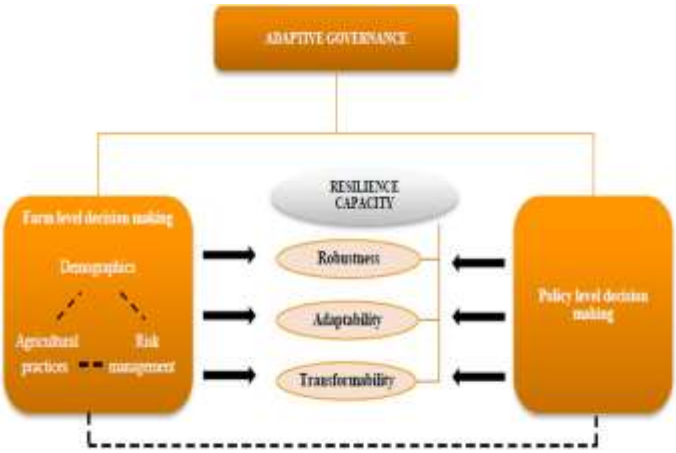
3. Concept of Community-Based Farming Groups

A Community-Based Farming Group (CBFG) is a group of farmers who come together voluntarily to tackle shared agricultural issues, maximize the utilization of available resources, and enhance their incomes. Such groups are avenues for convergence, allowing farmers to transcend limitations that they would find difficult to overcome as individuals. Through grouping, farmers improve their bargaining power, access to inputs, credit facilities, markets, and technology.

The major principles underlying CBFGs are:

Mutual Cooperation and Trust: Members cooperate in a spirit of solidarity, ensuring equal participation and sharing of benefits.

Collective Decision-Making: Production, marketing, and management decisions are made collectively, ensuring inclusivity and fairness.



Source: frontiersin

Resource Pooling and Risk Sharing: Financial, physical, and natural resources are shared to save costs and share risks of climate shocks, pests, and price instability.

Sharing of Knowledge and Skill: Ancient knowledge, new practices, and advanced technology are shared among members to encourage learning and innovativeness.

Examples of CBFGs are the Farmer Producer Organizations (FPOs), which pool produce for improved access to markets; Self-Help Groups

(SHGs), traditionally mobilized by women, which enhance financial inclusion and group farming; Cooperatives, which provide backing to members in terms of input supply and marketing; and Water User Associations, which manage irrigation in common for sustainable use.

4. Contribution to Building Resilience

Community-Based Farming Groups (CBFGs) contribute significantly to building the resilience of smallholder farmers against climatic, economic, and social risks. Through cooperation and collective action, they convert vulnerable communities into adaptive and sustainable farming systems.

a. Climate Resilience

CBFGs enhance climate-resilient agriculture through drought-resistant crop varieties, mulching, diversification of crops, and farming systems. Natural resources are maintained by communities in a collective manner by building check dams, harvesting rainwater, and establishing common irrigation systems. Group involvement in early warning systems makes preparedness for floods, drought, and pest infestation more effective, mitigating risk and loss.

b. Economic Resilience

Resource pooling allows farmers to obtain credit based on group guarantees, minimizing reliance on informal moneylenders. Collective marketing enhances bargaining capacity, insulating farmers from middlemen exploitation. Additionally, CBFGs provide storage facilities, processing units, and value addition businesses, which enable members to receive increased returns and stabilize incomes even in times of fluctuating markets.

Source: foodtank.

c. Social Resilience

CBFGs act as social protection mechanisms, cushioning poor households through difficult times. Capacity development programs and skill development enhance confidence and leadership within membership. Notably, the groups empower women by offering them decision-making authority and promote youth participation in new farming techniques, thus leading to generational succession in agriculture.

d. Knowledge Resilience

Farmer-to-farmer extension allows innovative and sustainable approaches to be disseminated. CBFGs blend indigenous knowledge with new technologies, with ease of adaptation to local environments. ICT tool access, mobile advisory services, and digital networks enable farmers to make informed choices, thus enhancing resilience against uncertainties.

5. Benefits of Community-Based Farming Groups

1. Lower Risk: Crop losses and financial risks are shared.
2. Economies of Scale: Joint procurement of inputs and shared machinery lowers costs.
3. Access to Finance: Banks and government schemes find them more appealing.
4. Market Linkages: Less difficulty in linking with buyers, exporters, and processors.
5. Policy Support: NGOs and governments find group-based interventions more appealing.

6. Case Studies / Best Practices

Actual life experiences show how Community-Based Farming Groups (CBFGs) have improved resilience and changed farm communities all over the world.

Case 1: Farmer Producer Organizations (India)

In India, Farmer Producer Organizations (FPOs) have been encouraged by the government and NABARD as a means to empower smallholders. Pooled resources enable farmers to collectively procure inputs and market produce like pulses, maize, and vegetables collectively. This minimizes costs with enhanced price realization. For example, one FPO in Maharashtra helped its members earn 20–

25% more returns through collective bargaining and direct marketing, demonstrating the potential of FPOs to enhance farm incomes.

Case 2: Women's Self-Help Groups (Kerala, India)

In Kerala, women Self-Help Groups (SHGs) have been able to adopt group vegetable farming on rented land. Not only did this improve food security at the household level, but it also provided supplementary incomes for the family. In addition to these economic advantages, engagement improved women's decision-making power, social standing, and self-confidence, leading SHGs to emerge as a significant model of gender empowerment in agriculture.

Case 3: Community Irrigation Groups (Africa)

Farmers in many African nations organized community irrigation groups to collectively manage small canals, dams, and water distribution. This helped improve water-use efficiency, minimized irrigation right conflicts, and provided fair access to limited water resources. Collective management of irrigation facilities minimized the cost of maintenance and ensured sustainability.

These illustrations highlight how CBFGs, be it in marketing, production, or the management of resources, play a major role in economic empowerment, social fairness, and resilience to climate, providing scalable models for sustainable agriculture.

7. Challenges Confronting Community-Based Farming Groups

Although Community-Based Farming Groups (CBFGs) have shown immense potential in enhancing resilience and livelihoods, a number of challenges constrain their capabilities and long-term sustainability.

One of the key problems is an absence of trust and intragroup conflict among members. Profits-sharing, decision-making, and unequal participation disagreements have a tendency to cause splits that disunite the group. Trust must be established and sustained but may prove challenging in multicultural communities.

Limited managerial and leadership abilities are another hindrance. Most groups do not have trained leaders who can manage financial accounts, organize group activities, and negotiate with outside parties. Without effective governance, mismanagement and inefficiency can occur.

Inadequate storage, processing, and transportation infrastructure is also a limitation. Limited access to cold stores, warehouses, or value-addition units limits the group's potential to reduce post-harvest losses and maximize higher profits.

Most CBFGs also demonstrate reliance on external support and NGOs. Although external help is usually beneficial to set up the groups, excessive dependency can render them unsustainable upon termination of the donor programmes.

Lastly, inadequate policy support in specific areas impedes the development of CBFGs. Uncertainty in government schemes, no access to subsidies, and bureaucratic red tape discourage involvement and restrict their performance.

8. Strategies to Strengthen Community-Based Farming Groups

To ensure long-term sustainability and resilience for Community-Based Farming Groups (CBFGs), strategic interventions are required. These interventions should aim at empowering members, enhancing governance, and facilitating enabling environments for collective action.

1. Capacity Building:

Leadership training programs, financial literacy training, record-keeping training, and marketing training programs are necessary. Technical and managerial capacity building will enhance decision-making, accountability, and efficiency in groups. Exposure visits and farmer-to-farmer learning can further enhance practical experience.

2. Policy Support:

Favorable laws, subsidies, and credit facilities by governments must be made available for group farming. Tax incentives or price support schemes,

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along with simplifying registration procedures, will attract greater participation. Institutional support will be increased by integrating CBFGs with national agricultural missions and rural development programs.

3. Infrastructure Development:

Investments in cold storage, warehouse facilities, processing units, and transport infrastructure are essential to minimize post-harvest losses and enhance access to markets. Common infrastructure guarantees economies of scale and facilitates value addition for better incomes.

4. Digital Tools:

Introduction of mobile applications, e-marketing platforms, and ICT-based advisory services will enable groups to access weather data, price information, and technical advice. Digital literacy initiatives will further empower members to engage productively in the digital economy.

5. Inclusion:

Ensuring active engagement of women, youth, and marginal groups promotes social sustainability and equity. Inclusive systems provide more solid social bonds and empower all segments of society.

9. Conclusion

Community-Based Farming Groups are a sustainable route to resilience in agriculture. Through sharing of resources, mitigation of risks, and establishment of robust social and market linkages, they enable farmers to bear impacts from climate, economy, and society. Improving these groups through training, policy assistance, and investing in infrastructure can be a transformative factor in constructing a resilient and autonomous farming community.

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Drone and Remote Sensing Applications in Crop Monitoring

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The fast-paced evolution of unmanned aerial vehicle (drone) and remote sensing technologies is transforming agriculture in the modern era by solving food security, climate change, and resource management issues. Both technologies offer real-time, accurate, and extensive field data on crop health, soil quality, water stress, and pest/disease prevalence, allowing farmers to implement timely and cost-saving interventions. Applications are in crop monitoring using vegetation indices (e.g., NDVI), scheduling irrigation using thermal sensors, soil and field analysis using high-resolution mapping, precise yield estimation, and assessment of crop damage after disasters for insurance purposes. Major benefits are enhanced accuracy, stress detection in advance, optimal resource use, and increased precision farming support. Adoption, however, is hindered by factors like high initial cost, requirement of skilled human resources, policy and regulatory issues, lack of connectivity, and operational limitations. Future trends emphasize linking with Artificial Intelligence (AI), Internet of Things (IoT), and big data, low-cost scalable model development, climate-smart implementation, digital crop insurance, and public-private alliances. By and large, drones and remote sensing are on their way to becoming critical technology for intelligent, data-dependent, and sustainable agriculture with the potential to revolutionize Indian and global farming systems.

Introduction

A technological revolution in modern agriculture is being experienced to address the increasing demands of food security, climate change, and resource management. Two of the most promising technologies are drones (Unmanned Aerial Vehicles) and remote sensing technologies, which are revolutionary in crop monitoring and precision farming.

These technologies enable farmers to obtain real-time, precise, and large-scale field information regarding crop health, soil status, water stress, and pest/disease infestation. In contrast to the conventional field scouting methods, which manually take a long time and require human effort, drones and remote sensing systems yield quick, low-cost, and highly detailed information that facilitates timely interventions.

By combining drones with remote sensing equipment like multispectral, hyperspectral, and thermal sensors, farmers are able to make data-driven decisions regarding irrigation scheduling, nutrient application, and pest management. This enhances efficiency and productivity but also achieves sustainability through reduction of wastage of inputs such as water, fertilizers, and pesticides. Thus, drones and remote sensing are revolutionizing the future of smart agriculture by making farming more data-intelligent, accurate, and robust.

Applications in Crop Monitoring

1. Crop Health Assessment

Multispectral and hyperspectral cameras fitted on drones can identify initial signs of infestation by pests, disease, or nutrient deficiency well before they are observable to the human eye. By computing vegetation indices like NDVI (Normalized

Difference Vegetation Index), farmers can accurately keep track of plant health, photosynthetic activity, and crop well-being. This facilitates timely intervention, lowering yield losses and input expenses.

2. Irrigation Management

Drone-mounted thermal sensors can detect areas of water stress in fields by measuring differences in leaf temperature. This enables targeted irrigation to be delivered only where it is required. This not only saves water but also enhances crop development and cuts energy for pumping expenses.

3. Soil and Field Analysis

Remote sensing information informs us about soil moisture levels, levels of organic matter, and topography of fields. Drones are able to create high-resolution 3D maps, helping in precision land preparation, seeding uniformity, and planning nutrient application. Farmers can also identify areas where soil erosion is likely to occur and plan conservation activities.

4. Yield Estimation

Drones provide data on canopy structure of crops, biomass growth, and development stages, which can be analyzed to estimate the yield precisely. This data assists in market planning, storage, and supply chain management, mitigating post-harvest uncertainty. It also assists policymakers and agribusinesses with predicting regional production levels.

5. Crop Insurance and Damage Assessment

Following natural disasters like floods, droughts, hailstorms, or cyclones, drones can quickly carry out aerial surveys. Such surveys offer credible and unbiased information for damage assessment, allowing farmers to file for insurance claims promptly. Government departments and insurance companies gain from precise, evidence-based estimations for compensation and relief disbursement.

Advantages of Drones and Remote Sensing in Agriculture

Precision in Crop Health Monitoring

Sophisticated imaging sensors and vegetation indices enable farmers to identify minute differences in crop vigor, making it possible to accurately evaluate plant health.

Time and Cost Savings

Drones enable the surveying of vast fields within a few minutes compared to traditional manual scouting, saving labor costs and offering immediate, actionable information.

Early Stress, Pest, and Disease Detection

Multispectral and hyperspectral imaging detects symptoms of stress at the early stage, allowing farmers to intervene in time and reduce yield losses.

Optimized Resource Use

With the precise location of water stress, nutrient starvation, or pest attack areas, drones assist farmers in applying inputs (water, fertilizer, pesticides) where needed, thereby conserving and saving resources and costs of production.

Support for Precision Agriculture and Smart Farming

Integration of drones with decision-support systems, IoT, and GIS increases precision farming practices, enhancing productivity, profitability, and sustainability.

Challenges in Adopting Remote Sensing and Drones in Agriculture

High Initial Investment

Acquisition of multispectral sensors and drones along with necessary software involves substantial capital, and small farmers cannot invest in the technology without subsidies or cooperative models.

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Need for Skilled Manpower

Operation of drones and processing remote sensing data need technical knowledge and skill. Limited capacity-building initiatives in the countryside hamper effective uptake.

Policy and Regulatory Barriers

Drone operation in agriculture is still taking shape within India's regulatory platform. Licensing, permission for flights, and restriction on safety tend to hinder or postpone extensive uptake.

Connectivity and Data Processing Issues

Remote areas often have poor internet connectivity and no advanced data analytics capabilities. This slows down real-time transmission and analysis of data captured by drones.

Maintenance and Operational Challenges

Hostile field conditions, weather dependency, and frequent maintenance contribute to operational challenges, especially for small-scale operators.

Future Directions

Synergy with AI and IoT

The integration of drone technology with Artificial Intelligence (AI), Internet of Things (IoT), and big data analysis will facilitate real-time decision support for irrigation, fertilizer application, and pest management.

Low-Cost and Scalable Solutions

Low-cost drone development, rental models, and collective ownership schemes will ensure that this technology is within reach of marginal and smallholder farmers.

Climate-Smart Agriculture

Drones will become a critical tool in crop stress monitoring due to weather extremes, facilitating adaptation measures that increase climate change resilience.

Digital Crop Insurance and Monitoring

Increased application of drones to crop insurance surveys, government monitoring initiatives, and disaster evaluation will provide transparency, quicker settlement of claims, and enhanced policy planning.

Public-Private Partnerships (PPP)

Increased partnerships among startups, research organizations, and governments can help hasten innovation, uptake, and farmer training.

Conclusion

Drone and remote sensing technologies are transforming crop monitoring through provision of timely, precise, and actionable information to both farmers and policymakers. They minimize the reliance on manual scouting, increase efficiency, and aid precision farming practices that conserve resources and improve yields.

With favorable policies, low-cost solutions, and capacity development programs, these technologies can enable farmers to make informed decisions based on data, minimize risks, and transition towards sustainable and climate-resilient agricultural development.

Over the next few years, drones will not only be used to monitor but will become a core part of smart farming systems and be the wave of the future for agriculture in India and around the globe.

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Gender Equity in Extension Services: Making Training Inclusive

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Gender equity in extension services is critical to ensuring that both women and men farmers share the same benefits from agricultural innovation and training. Women, although they make important contributions to agriculture, face challenges like lack of access to resources, little or no representation in decision-making, cultural limitations, and training programs that are not designed for their needs. Extension strategies that are inclusive in nature gender-sensitive training plans, hiring female extension agents, participatory program development, and utilizing ICT tools can address these issues. There is evidence from a number of case studies that gender-responsive extension results in higher farm productivity, household food security, and women's empowerment, which contribute directly to sustainable development objectives. Policy support, institutional mechanisms, and monitoring systems need to be strengthened for gender equity to be embedded in extension services. Including training makes it not just more equitable but also more effective and sustainable for overall agricultural development.

Introduction

Extension services for agriculture are crucial in disseminating scientific information and innovations to agricultural communities. However, in most areas, such services do not adequately meet the needs of women farmers, who make up almost half of the farmers. Sustained gender gaps in resource access, decision-making, and training limit women's ability to contribute meaningfully to agricultural development and food security. Attaining gender equality in extension services involves providing equal opportunities for men and women while recognizing their unique roles, challenges, and needs. Developing inclusive and gender-sensitive training equips women, improves their decision-making power, and enhances household livelihoods. These methods end up enhancing productivity, enhancing food security, and increasing resilience, making agriculture more equitable and sustainable.

2. Gender Roles in Agriculture

Women are integral to agriculture, engaging in varying roles throughout crop production, livestock management, post-harvest processing, and home food management. From seed choice and planting to weeding, harvesting, storage, and preparing foods, women are involved. Besides, women are at the forefront in rearing livestock, milk production, poultry farming, and kitchen gardens that feed families. Most of women's work in agriculture is invisible, unpaid, and undervalued both within and outside households.

Extension services tend to neglect women and regard men as main farmers and decision-takers. This restricted recognition hinders women from achieving access to vital knowledge, training, and innovations that can increase their productivity and earnings. For instance, in South Asian and African settings, men tend to control cash crop planning and market access, while women are largely responsible for food crops and home gardens. However, without focused extension support, women's capacity for yield improvement, adopting new technologies, or enhancing food security is heavily impeded. Identifying and responding to these gender roles is essential to constructing inclusive and effective extension services.

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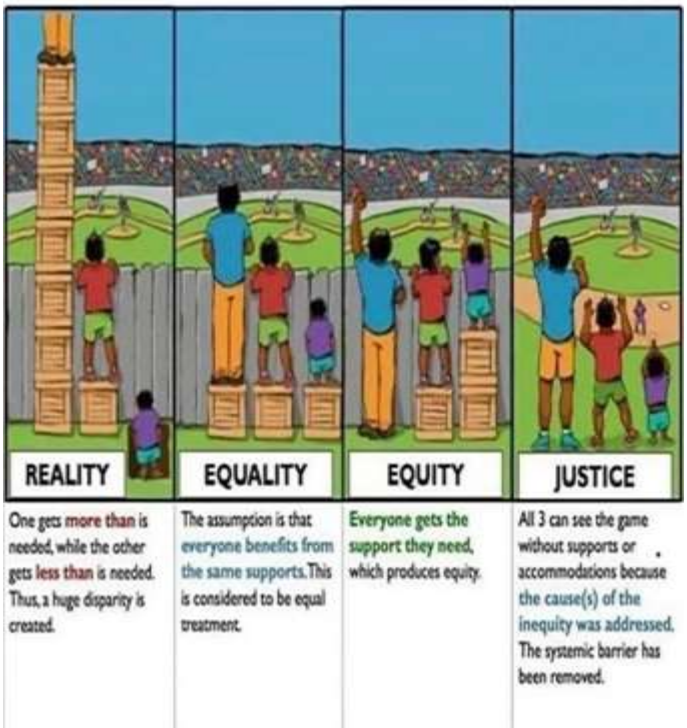

Source: dcdualvet

3. Barriers to Gender Equity in Extension Services

While women contribute significantly to agriculture, they are confronted with several obstacles that constrain their access to extension services. Among the strongest of these is cultural and social norms. Women's mobility in many rural communities is highly controlled, and farmer groups or cooperatives are dominated by men, thus denying women a voice in decision-making.

The other challenge is the non-representation in extension systems. The percentage of female extension workers remains very low, and most women farmers are not at ease to interact with male trainers based on cultural sensitivities. The gap lowers women's exposure to crucial agricultural knowledge and innovations.

Time and work constraints are also hindrances. Women bear the double burden of domestic chores, child care, and farm work, with no time to spare for trainings or demonstrations. In addition, restricted access to resources such as land ownership, credit, inputs, and technology often under men's control, also diminishes their ability to embrace new practices.

Lastly, training design problems also limit participation. Programs are usually arranged at inopportune hours, distant from villages, or presented in modes inappropriate for women learners. Until these obstacles are resolved, women will continue to be excluded from agricultural extension services.

Source: humanrightscareers

4. Approaches to Making Training Inclusive

Achieving gender equity in extension services calls for embracing approaches making training more accessible, inclusive, and relevant to female farmers.

Gender-sensitive training programmes are the initial step. Training timetables need to be tailored to accommodate women's daily duties, usually best scheduled in the afternoons or near their villages. Local venues, including centres and schools, minimize travel obstacles, while the availability of childcare facilities during sessions ensures women attend without abandoning family responsibilities.

Boosting the hiring of women extension workers is also crucial. Women trainers have the capacity to bridge cultural divides, facilitate participation, and act as models. Educating female employees in topics like nutrition, food processing, and small livestock management guarantees that women farmers get a response that caters to their needs.

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Participatory methods strengthen inclusiveness through proactive engagement of women in need identification, program planning, and outcome evaluation. Farmer Field Schools (FFS) and Self-Help Groups (SHGs) can be used as platforms to facilitate balanced participation, sharing of information, and peer learning.

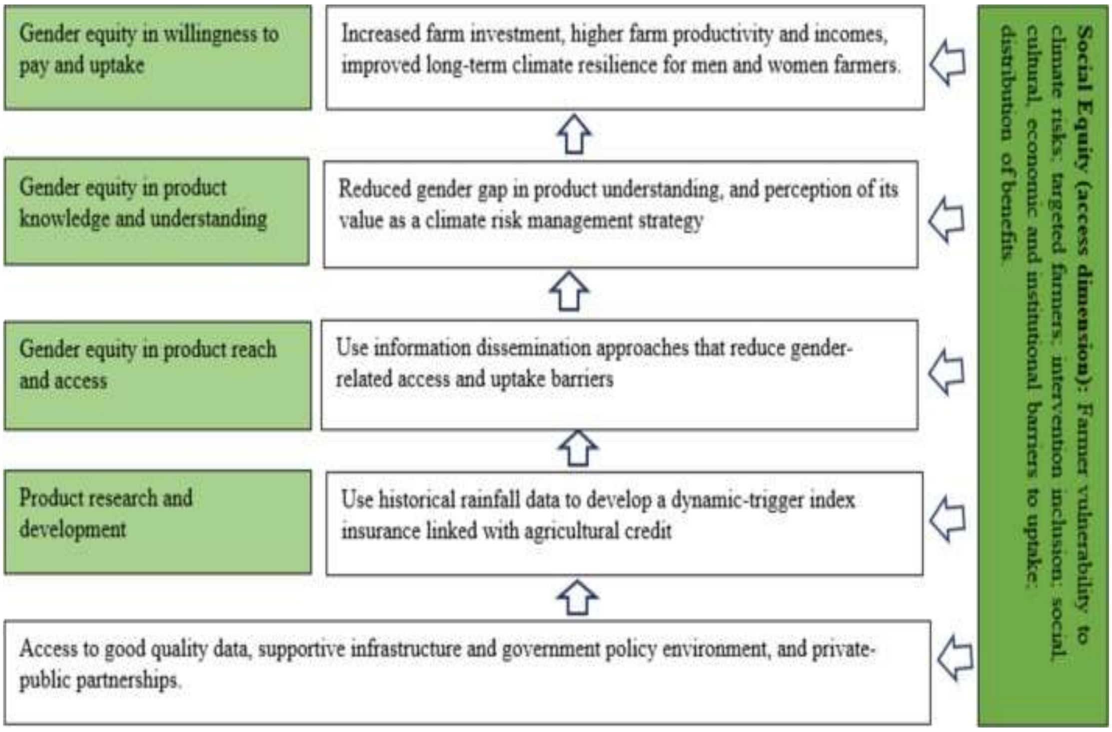
The application of ICT and online platforms widens women's reach for extension services. Advisory services via mobile phones, WhatsApp forums, and community radio stations can provide information to women in real time. Voice messages, visual messages, and local languages make the information more accessible, particularly to women with poor literacy.

Leadership training and capacity building enable women to transition from participation to leadership. Training women in market access, financial literacy, record-keeping, and technical skills enhances their confidence and decision-making abilities. Role models for others are created through promoting women leaders in farmer groups and cooperatives.

5. Case Studies and Best Practices

A number of successful experiences globally demonstrate how gender-inclusive extension approaches can empower women and enhance agriculture outcomes.

In India, the Mahila Kisan Sashaktikaran Pariyojana (MKSP) has been an effective model of women-focused extension. The scheme emphasizes training rural women farmers, forming them into groups, and connecting them to markets and credit organizations. Through facilitating women's collective action, MKSP has increased their access to resources, enhanced farm productivity, and improved their bargaining power in local markets.



Source: https://www.sciencedirect.com/science

In Kenya, implementation of Farmer Field Schools (FFS) with a conscious attempt at involving equal proportions of men and women has been found to be life-changing. These schools not only imparted technical skills but also facilitated group meetings where women were able to actively contribute to decision-making. This caused the confidence of women in crop management practices to increase, and they became more involved in family agricultural decisions.

In Bangladesh, the deployment of female extension agents has had a considerable impact on women's involvement in training programs on livestock and poultry. Female farmers were more at ease talking to women trainers, which enhanced the adoption of new technologies leading to improved livestock health and household incomes.

6. Advantages of Gender-Inclusive Extension

Encouraging gender equity among extension services has several advantages above and beyond individual farmers and has direct benefits for households, communities, and national development efforts.

Perhaps the most obvious result is increased productivity. When women farmers have equal access to training, new technologies, and inputs, they are more capable of adopting better practices, resulting in more yields and effective use of resources. It has been shown by studies that reducing the gender gap in agriculture can greatly improve farm output overall.

Household food security is a second significant advantage. Women have a tendency to emphasize food crops, home gardens, and nutritional content. With improved knowledge and resources, families gain more varied diets, better availability of food, and healthier children and families.

Gender-inclusive extension also results in social empowerment. Involvement of women in training and decision-making increases their confidence, enhances leadership positions, and enhances their power to influence household and community-level crop choices. This empowerment results in increased equity in rural society.

Finally, inclusive extension has a direct role in the Sustainable Development Goals (SDGs), specifically SDG 5 (Gender Equality) and SDG 2 (Zero Hunger). By promoting equal women's participation in agriculture, extension services are supporting wider objectives of poverty alleviation, nutrition security, and sustainable development.

7. Implementation Challenges

Even with progress, a number of challenges constrain effective implementation of gender-equitable extension services. Rooted gender stereotypes in rural societies tend to limit women's mobility, voice, and access to training programs. Inadequate funding for gender-specific initiatives further compromises efforts toward designing and maintaining inclusive programs. Finally, there is a lack of adequate monitoring and evaluation of women's engagement in extension activities, which makes it challenging to measure actual impact. Another key gap is the absence of gender-disaggregated data, which hinders evidence-based planning and targeted interventions. Unless these obstacles are tackled, gender equality in extension remains more of a policy idea than an attainable reality.

8. Recommendations

In order to make agricultural extension services more gender-equitable, there needs to be a set of concrete recommendations implemented. First, gender analysis needs to be mainstreamed in all extension projects. This will enable determination of the particular needs, challenges, and opportunities for women farmers, ensuring programs are devised with the purpose of effectively addressing them.

- Second, the availability of women-friendly technologies like lightweight farm tools, seed kits, and small-scale processing equipment can facilitate women's work reduction and increase productivity. Equally crucial is making these technologies available and affordable.
- Third, introducing quota systems can ensure women's participation in training sessions, farmer groups, and decision-making forums. These interventions will stimulate equal participation and foster inclusivity.
- Fourth, having solid partnerships with NGOs, self-help groups (SHGs), and women's cooperatives can improve outreach, offer additional support systems, and facilitate scaling up successful practices. These partners tend to have stronger community connections and trust among women farmers.

- Finally, gender awareness and sensitivity training for extension staff is essential. This will make the extension workers aware of gender dynamics, steer clear of biases, and implement practices that proactively benefit women farmers. All these measures in combination will enhance inclusivity and enhance the efficacy of extension services.

9. Conclusion

Gender equality in extension services is not merely a question of justice but a key to sustainable rural development. Inclusive training, taking into consideration and addressing the needs of women, guarantees that all segments of society benefit from agricultural innovation. By addressing extension services as gender-responsive, we can boost productivity, enhance household well-being, and speed up progress towards global food and nutrition security.

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Bee-Keeping as a Secondary Source of Farm Income

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Apiculture or bee-keeping is a low-cost, sustainable business that offers farm families additional income as well as increasing agricultural productivity by providing pollination services. Aside from honey, which is still the main product highly prized for its medicinal and nutritional value, secondary bee products like beeswax, royal jelly, propolis, pollen, and new products like bee venom also play important roles in farm income diversification. Scientific research reveals that honeybee pollination is able to enhance crop yields by 15–200%, enhancing food security and marketable quality. Apiculture offers employment opportunities, especially to small and marginal farmers, rural youth, and women, with little land requirement and infrastructure. From an environmental perspective, bee-keeping makes significant contributions to the conservation of biodiversity and climate-resilient agriculture. With growing domestic and export demand for natural and value-added products, with the encouragement of the government through training, subsidies, and the National Beekeeping and Honey Mission, apiculture is becoming a promising secondary livelihood strategy improving resilience, sustainability, and rural prosperity.

Introduction

Bee-keeping (apiculture) is an ancient agronomic practice which consists of the scientific management of honeybee colonies for the production of honey, beeswax, royal jelly, propolis, pollen, and other hive products. Honey and its by-products are greatly valued due to their nutritional, medicinal, and industrial applications, and apiculture thus forms an essential part of integrated farming systems. In addition to the actual production of honey, the most significant contribution of bee-keeping is in pollination services that greatly increase the yield, quality, and uniformity of fruits, vegetables, oilseeds, pulses, and plantation crops.

Apiculture involves moderate investment and minimal infrastructure, and so even small and marginal farmers can adopt it. If only trained and scientifically managed, farmers are able to earn a sustainable supplementary income without necessarily owning large areas of land. As bees collect nectar and pollen from natural cover, orchards, as well as cultivated fields, bee-keeping can be carried out in nearly all agro-climatic zones.

Furthermore, bee-keeping encourages environmental sustainability through the preservation of biodiversity and ecosystem services. It provides scope for entrepreneurship, self-employment, and rural women empowerment, particularly when combined with ongoing farming enterprises like horticulture, floriculture, agroforestry, and organic farming. With increasing demand for natural produce and pollination services, bee-keeping has become a viable secondary enterprise with potential to enhance farmers' resilience towards crop loss and market price fluctuations.

Significance of Bee-Keeping

Supplementary Income

Bee-keeping provides farmers with a means of diversifying their livelihood sources. The main produce, honey, is always in demand for nutritional, medicinal, and industrial purposes. Apart from this, honey's by-products like beeswax (applied in cosmetics, pharmaceuticals, and candle production), royal jelly (a health supplement), propolis (antimicrobial), and pollen (a protein-based dietary supplement) also generate multiple incomes. Apiculture, therefore, guarantees a consistent stream of cash income with relatively minimal cost of production.

Crop Pollination

One of the most valuable services of honeybees is natural pollination. Bees improve fruit set, seed set, and quality in cross-pollination-dependent crops such as mustard, sunflower, cucurbits, apple, mango, litchi, citrus, and other fruits and vegetables. Science has established that bee pollination can raise crop yields by 15–200% depending on crop species. Not only does it increase food production but also the uniformity, size, and marketability of agricultural produce.

Employment Generation

Bee-keeping is a viable livelihood opportunity, especially for rural youths, women, landless farmers, and small farmers. It is possible to undertake it as a part-time or seasonal enterprise without interfering with normal farm activities. The comparatively easy skills involved can be transferred quickly using short-term training schemes. Bee-keeping ventures also provide indirect employment in equipment manufacturing, honey processing, value addition, and marketing, thereby enhancing the stability of rural economies.

Low Investment and High Returns

Apiculture is a low-input venture that does not need fertile farmland ownership. The minimum equipment comprises bee boxes, protective gear, and easy tools. Bees forage for nectar and pollen from the surrounding environment, hence feed and raw material expenses are minimal. Farmers can achieve high returns with low inputs in a short time, making it particularly favorable to poor farming communities.

Environmental and Ecological Benefits

Bee-keeping plays a crucial role in ensuring ecological balance and biodiversity. Honeybees are significant pollinators of wild vegetation, contributing to the conservation of native plant species and wildlife habitats. Through cross-pollination, bees help forest, grassland, and agro-ecosystem regeneration. This positions apiculture as a key part of climate-resilient agriculture, enabling sustainable development goals (SDGs) like food security, poverty alleviation, and environmental sustainability.

Scope for Value Addition and Export

With growing health consciousness and demand for natural products, the world honey market is growing at a fast pace. India, being geographically diverse with various flora and climatic conditions, has a great potential to emerge as one of the major honey and bee product exporters. Value-added products such as flavored honey, beeswax candles, medicinal blends of honey, and cosmetics also increase profitability and market opportunities.

Products of Bee-Keeping

Honey

Honey is the main product of bee-keeping, a health food as well as a natural sweetener. It is rich in carbohydrates, enzymes, amino acids, vitamins, minerals, and antioxidants, rendering it a source of energy that enhances immunity. Honey finds extensive uses in domestic consumption, traditional medicine (Ayurveda, Unani, Homeopathy), pharmaceuticals, bakery, confectionery, and soft drinks. Medically, honey is used for its antimicrobial, anti-inflammatory, and healing qualities. Its growing demand in health-oriented markets has boosted both local and foreign demand.

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Beeswax

Beeswax is a precious by-product excreted by honeybees to construct comb cells. Beeswax is applied widely in cosmetics (lip balms, creams, lotions), pharmaceuticals (ointments, capsules), candle manufacturing, polishes, coatings, and textiles. Pure beeswax commands a high commercial price due to its toughness, non-toxicity, and fragrance. Farmers and business people also produce value-added items such as beeswax candles, soap, and ornaments for local sale.

Royal Jelly

Royal jelly is a secretion of worker bees to feed queen bees and larvae. Rich in proteins, lipids, vitamins, amino acids, and bioactive compounds, royal jelly is one of the most potent natural health supplements. Extensively used as a dietary supplement and nutraceutical, it is presumed to slow aging, increase immunity, boost fertility, and decrease fatigue. With rarity and medicinal value, there is a high price for royal jelly in domestic and foreign health industries.

Propolis

Propolis, also referred to as "bee glue", is a resinous product gathered by bees from tree bark and buds. Bees employ it to cement cracks in the hive, but for humans, it is very prized for its antimicrobial, antifungal, antiviral, and anti-inflammatory qualities. Propolis finds application in pharmaceutical preparations, oral hygiene products (toothpaste, mouthwash), skin ointments, and dietary supplements. In alternative medicine, it is also considered to be a natural immune stimulant and wound healer.

Pollen

Collected pollen by bees is a protein-rich dietary supplement, enriched with essential amino acids, vitamins, and enzymes. It is a superfood due to its function in enhancing stamina, metabolism, and general well-being. Bee pollen is largely sold as a dietary supplement, energy drink, and sports nutrition supplement. Moreover, pollen plays a significant role in scientific research, for instance, biodiversity studies, crop pollination, and food quality.

Other Emerging Products

- ✓ Bee Venom: A niche product with possible applications in the treatment of arthritis, multiple sclerosis, and other inflammatory conditions. It is also applied in cosmetics and alternative medicine.
- ✓ Comb Foundation Sheets: Made from beeswax and utilized by beekeepers for hive maintenance.
- ✓ Value-Added Honey Products: Flavored honey (ginger, lemon, tulsi, etc.), creamed honey, and honey-based drinks are popularizing in niche markets.

Products of Apiculture

Honey is the major commercial product of apiculture and is a highly prized healthy food and natural sweetener. Honey has carbohydrates, enzymes, amino acids, vitamins, minerals, and antioxidants, which render it an energy-dense food that is used to improve immunity. Honey finds various uses in domestic consumption, traditional system of medicine like Ayurveda, Unani, and Homeopathy, pharmaceuticals, bakery, confectionery, and beverages. Medicinally, honey is known for its antimicrobial, anti-inflammatory, and wound-healing characteristics. Its popularity among health-conscious consumers has stimulated domestic as well as international demand.

Beeswax is yet another by-product of apiculture, exuded by honeybees to form comb cells. Beeswax is in huge demand in cosmetics like lip balms, creams, and lotions, as well as in pharmaceutical industries for ointments and capsules. In addition to this, it is used in candle manufacturing, polishes, coatings, and textile production. Due to its resilience, non-toxicity, and good smell, pure beeswax has a high commercial value. Farmers and businesspersons may also diversify earnings by manufacturing value-added products like beeswax candles, soap, and beauty items for domestic markets.

Royal jelly, a unique secretion from worker bees for feeding queen bees and larvae, is one of the strongest natural health supplements. It contains proteins, lipids, vitamins, amino acids, and bioactive compounds. It is used extensively as a nutraceutical and dietary supplement and is thought to boost immunity, slow aging, enhance fertility, and combat fatigue. Due to its scarcity and medicinal significance, royal jelly commands a good price in both the local and foreign markets.

Propolis, also referred to as "bee glue," is a resinous material gathered by bees from tree bark and buds. Bees seal hive cracks using it, but for humans, it is of great value because it possesses antimicrobial, antifungal, antiviral, and anti-inflammatory properties. Propolis finds application in pharmaceutical products, oral care agents such as toothpaste and mouthwash, skin ointments, and natural health supplements. In alternative medicine, it is considered a natural immune stimulant and wound healer.

Pollen, the other product gathered by bees, is a protein-rich dietary supplement with essential amino acids, vitamins, and enzymes. It is seen as a superfood with a significant function in enhancing stamina, metabolism, and general well-being. Bee pollen is commonly marketed as a dietary supplement, energy booster, and sports nutrition supplement. In addition to this, it also has scientific value in biodiversity research, crop pollination research, and food quality determinations.

Aside from these principal products, bee-keeping also offers other new products with great promise. Bee venom, for instance, is becoming increasingly recognized for its application in the curing of arthritis, multiple sclerosis, and other inflammatory conditions, as well as cosmetics and alternative medicine. Comb foundation sheets, made from beeswax, are vital to effective hive management. Value-added honey products, including flavored honey with ginger, lemon, or tulsi, and creamed honey and honey-based drinks, gain popularity in niche health and well-being markets.

Economic Benefits

Bee-keeping is a very lucrative venture if scientifically managed, as it yields direct revenue from bee products and indirect revenue in the form of increased crop production. A well-cared for bee colony can produce 20–25 kg honey per annum, depending on the availability of flora, climatic conditions, and management practices. As increasing consumer knowledge about the health value of honey, it is selling at premium prices in local rural marketplaces, chain stores, and global trade. As one of the major honey-producing countries, India also has huge opportunities to expand its share in the global honey market.

Aside from honey, a number of by-products like beeswax, propolis, royal jelly, pollen, and bee venom command high commercial worth. Beeswax, for one, has widespread applications in cosmetics, pharmaceuticals, and candle manufacturing industries alone, while propolis and royal jelly are being sold as high-end health supplements. These by-products offer another source of cash income for farmers, which promotes diversification of farm-based livelihoods.

One of the greatest economic returns from bee-keeping is through pollination services. Honeybees improve fruit set, seed formation, and quality of various cross-pollinated crops such as mustard, sunflower, cucurbits, apple, and litchi. According to scientific research, bee pollination can increase yields by 20–30% or even more, which contributes to increased farm productivity and profitability. Bees play an even more critical role in horticultural crops since enhanced pollination directly affects the size, shape, and market value of fruits.

One of the advantages of bee-keeping is its low investment demand and high yield potential. Unlike most agricultural ventures, bee-keeping does not require extensive landholdings or high-value inputs. It can be successfully taken up by marginal and small farmers, women, and rural youth as a secondary or part-time venture. With very little cost involved in maintenance and the potential for multiple picks within a single year, the benefit–cost ratio of bee-keeping is usually higher than most conventional crops.

Additionally, the increasing production of value-added products and export markets has further enhanced the economic prospects of apiculture. Flavoured honey, organic honey, cosmetics made of beeswax, and pollen supplements are being increasingly demanded in domestic and international markets. With government programs like the National Beekeeping and Honey Mission (NBHM) offering financial support, training, and infrastructure, farmers are able to include bee-keeping in their farming systems for sustainable and increased income.

Steps to Successful Bee-Keeping

Selection of the Bee Species

The selection of the bee species is the initial step to successful bee-keeping. In India, some of the species utilized for apiculture are the Indian honeybee (*Apis cerana indica*), which is well suited to local conditions and is easy to maintain; the European or Italian bee (*Apis mellifera*), which is very productive and extensively utilized in commercial bee-keeping; and rock bee (*Apis dorsata*), which is a wild bee species with high honey production but hard to domesticate. Choosing the appropriate species varies with the area, climate, floral resources, and the experience of the farmer.

Apiary Site Selection

The position of the apiary is of utmost importance to the success of bee-keeping. The apiary site should be sunny, well-drained, ideally with natural windbreaks, and far from waterlogged areas, industrial pollution, and fields sprayed with pesticides. Bees need to have access to diversified and copious floral resources of nectar and pollen year-round. Hence, apiaries must ideally be placed close to orchards, vegetable lands, forests, or plantations. Access to a clean water source in the vicinity is as crucial for colony health and productivity.

Management Practices

Good management is necessary to have healthy, strong, and productive bee colonies. This involves frequent hive inspections to check on development of brood, honey storage, and queen bee performance. Successful pest and disease control are essential to keep at bay threats such as wax moths, Varroa mites, and bacterial or fungal infections. Seasonal management techniques like offering artificial feeding during periods of dearth and carrying out seasonal relocation of colonies to regions with high floral densities (e.g., mustard fields, litchi orchards, or eucalyptus plantations) aid in honey output maximization. Regular colony strength and queen replacement with healthy ones are also significant practices.

Harvesting and Processing

Honey harvesting must be executed at the appropriate time when combs are well-filled and capped. The bees have to be handled gently to prevent killing them and ensuring the honey quality. Honey extractors are mostly applied for effective extraction. Honey, after harvesting, has to be handled hygienically, filtered to eliminate impurities, and stored in clean, tight containers to avoid fermentation or crystallization. In addition to honey, other hive products such as beeswax, propolis, and pollen must be harvested and handled properly in order to preserve their quality and market value.

Marketing and Value Addition

Marketing is the last but the most important step towards successful bee-keeping. Farmers must try to connect with cooperatives, farmer producer organizations (FPOs), self-help groups, and government-sponsored marketing outlets for equitable and guaranteed prices. Direct sales from farms to consumers via farm-gate sales, local markets, organic stores, or websites can also command premium prices. Further, value addition of raw products into final products like flavored honey, beeswax candles, herbal honey blends, and cosmetic items will bring significant income. Export of organic and medicinal honey varieties further opens up opportunities for wider markets.

Government Support

The Government of India has realized the vast potential of bee-keeping in enhancing farm revenues, pollination service, and rural employment. For promoting this industry, various schemes, programs, and institutional supports have been initiated:

National Bee Board (NBB): The NBB is a driving force in the development of apiculture in the nation. With the National Beekeeping & Honey Mission (NBHM), it offers financial support, subsidy, and technical aid for setting up bee colonies, improved hives, processing units, quality testing laboratories, and value addition facilities.

Mission for Integrated Development of Horticulture (MIDH): Under this mission, farmers are assisted with the purchase of bee boxes, machinery, and protective clothing. Emphasis is given specifically to incorporating bee-keeping with plantation crops, horticulture, and floriculture to increase productivity through pollination.

Skill Development and Training Programmes: Krishi Vigyan Kendras (KVKs), State Department of Agriculture, and ICAR institutes conduct training programmes, demonstrations, and workshops on scientific beekeeping on a regular basis. These training programmes impart practical skills in managing the colony, harvesting honey, controlling pests, and marketing to farmers, rural youth, and women.

Credit and Financial Support: Farmers are also eligible to obtain loans and credit schemes under NABARD's schemes and other rural banks for the establishment of apiaries and honey processing plants. Most states offer extra subsidies for women entrepreneurs, small and marginal farmers, and self-help groups as well.

Quality Assurance and Marketing Support: The government is making efforts towards standardization and branding of Indian honey through FSSAI certification, Agmark grading, and export facilitation. This enables farmers to get better prices in domestic and global markets. Programs like "Sweet Revolution" have further underlined the potential of bee-keeping as a tool for doubling farmers' income.

Conclusion

Bee-keeping is not merely honey production it is a viable, environment-friendly, and remunerative business that supports conventional farm systems. By optimizing pollination efficiency, bee-keeping improves crop yield and quality, thus contributing to national food security. It involves relatively low investment and little land use, so it is a suitable secondary livelihood for small and marginal farmers, rural youth, and women.

With the use of advanced scientific practices, farmers are able to optimize productivity and make disease-free, high-quality bee products. Moreover, the increasing international and domestic demand for natural and organic products gives Indian farmers access to lucrative domestic and export markets.

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Subsidies, training, access to credit, and market promotion by the government have rendered bee-keeping an economic and appealing venture. Through taking advantage of these programs and adopting innovative farming practices, farmers are able to diversify their income streams, enhance rural livelihoods, and support conservation of biodiversity and ecosystem integrity.

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Beyond the bowl: Assessing the environmental and social impacts of rice cultivation in Odisha

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As a Major producer and consumers of rice (Oryza sativa), Odisha enjoys a significant advantage in rice cultivation for its favorable climate, fertile soil, and abundant water resources. Rice farming is particularly important for the state's agricultural sector, where the majority of farmers are small and marginal. However, despite many benefits that rice cultivation offers, it also presents several challenges and drawbacks for farmers and the environment. This article highlights those issues and explores solutions to promote more sustainable and resilient rice farming in Odisha.

Introduction

India is a major cereal-producing country. In 2024, the total area under rice cultivation across India was recorded at 47.6 million hectares. Of this, Odisha alone accounts for approximately 39.5 lakh hectares (covering both *kharif* and *rabi* seasons), representing about 69% of the state's total cultivated area. During the 2021–22 period, Odisha produced around 138 lakh tons of paddy, equivalent to roughly 92 lakh tons of rice. Odisha is an agriculture-oriented state, with about 60% of its population engaged in farming. Rice is vital to Odisha's economy and nutrition. However, rice cultivation in Odisha also possesses several environmental and agronomic challenges. These include soil degradation, greenhouse gas emissions, a falling groundwater table and other related issues. These negative effects not only impact the environment but also have serious implications for the long-term sustainability and well-being of the farming community. This article examines these challenges and discusses potential solution.

Odisha's Overreliance: The Prevalence of Monoculture

Due to the limited availability of resources in Some areas of Odisha, many farmers prefer monoculture of Rice as rainfed crop. This excessive reliance on rice monoculture has led to significant soil related issues. Rice is a high nutrient demanding crop, particularly in its uptake of nitrogen from the soil. Continuous rice cultivation depletes essential nutrients, resulting in declining soil fertility over time and degradation of overall soil health. Since rice cannot fully meet its nutrient needs from the soil, farmers increasingly depend on chemical fertilizers to sustain yields. However, prolonged and excessive use of these fertilizers further deteriorates soil quality and structure.

Puddling: Creating Concern, Rising Emission

Cultivation of paddy traditionally requires waterlogged condition for better growth and optimal yield. However, these waterlogged or flooded fields become significant sources of methane (CH_4) emissions. The standing water creates anaerobic (oxygen-deficient) conditions in the soil, that are ideal for methanogenic bacteria. These bacteria break down organic matter in the absence of oxygen and release methane as a byproduct. Several factors including soil type, organic matter availability, ambient temperature, fertilizer application and the amount of water used influences methane emissions from paddy fields. Methane is a potent greenhouse gas, and its release into the atmosphere contributes significantly to global warming, resulting in rising temperatures, changes in weather patterns and other climate-related hazards.

The Deteriorating Fields: Soil degradation

Odisha faces significant soil degradation challenges in its paddy fields. The continuous practice of paddy cultivation combined with the use of intensive farming methods and heavy machinery has contributed to the degradation of cultivable land, the use of heavy machinery and the continuous puddling of fields for rice cultivation also contribute to soil compaction. Compacted soil has reduced porosity and a lower infiltration rate, which restricts root growth and limits nutrient uptake by plants. Degradation of land due to soil salinization is a major issue seen in coastal parts of Odisha. Excessive irrigation and inadequate drainage lead to the accumulation of salts in the soil. Salinization reduces soil fertility and makes the land unsuitable for cultivation. Moreover, the heavy reliance on chemical fertilizers disrupts the soil's natural nutrient balance and leads to a decline in beneficial soil microorganisms.

Clearing Fields; Clouding Skies- The harmful effects of crop residue burning

Paddy cultivation generates large quantities of paddy straw and crop residues. The straw-to grain ratio typically ranges from 1:1.2 to 1:1.5, meaning that for every kilogram of rice, more than a kilogram of straw is produced. To quickly clear fields for the next cropping cycle, farmers often burn these residues directly in the fields. This practice contributes significantly to the increase in greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2), methane

(CH_4), and nitrous oxide (N_2O), all of which contributes towards climate change. In some cases, crop residues are also burned to control insect pests and weeds, but this short-term solution comes at a high cost. Straw burning is becoming a major source of air and water pollution, that leads to a wide range of environmental and health problems, including poor air quality, soil degradation and loss of soil organic matter, reduced atmospheric visibility, contributing to road accidents, respiratory issues such as asthma and bronchitis.

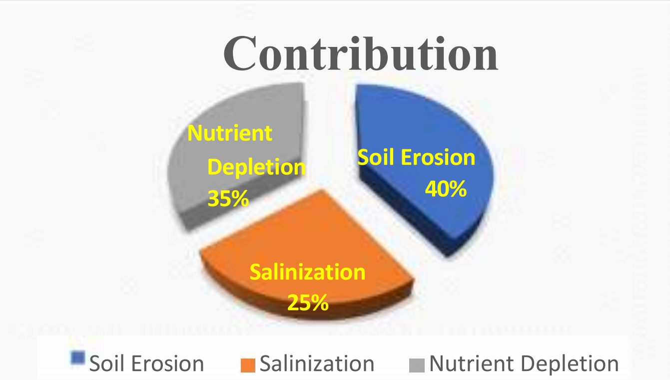

Fig. Showing soil degradation due to rice cultivation in Odisha

Potential solutions to these problems: Diversification dynamics;

To reduce the adverse impacts of monoculture in Odisha, several sustainable strategies can be adopted.

1. Low-cost intercropping - minimal inputs and investment, suitable for small and marginal farmers.
2. Crop rotation - easily available legumes can help improve soil health and maintain soil fertility.
3. Promoting the cultivation of upland crops such as cassava (*Manihot esculenta*), yambean (*Pachyrhizus* spp.), ginger (*Zingiber officinale*), and turmeric (*Curcuma longa*) etc. can be highly beneficial.
4. Integrating livestock and poultry into small scale farms reduced dependence on a single crop.
5. Procurement of seeds from community seed banks and growing of local seed varieties - Reduce input costs and increase resilience.
6. Support by Government- Providing Subsidies and Incentives.

Reducing Rice footprint

Implementing Alternate Wetting and Drying (AWD) in rice cultivation involves partially draining the paddy field at specific intervals, which allows the soil to aerate and reduces the anaerobic conditions that typically develop due to continuous water stagnation. This practice significantly lowers methane (CH_4) emissions, improves water use efficiency and reduces the total water consumption in rice fields. Another effective method is mid-season drainage, which involves temporarily draining the field during the growing season. This practice can also lead to a substantial reduction in methane emissions. In addition, the proper management of crop residue such as composting, mulching, or using them as biofuel or fodder is essential to prevent open field burning and to further reduce CH_4 emissions from paddy fields.

Healthy soil - Happy harvest

To reduce the rate of land degradation, several measures should be taken including efficient Integrated Nutrient Management (INM), incorporating organic manures such as Farm Yard Manure (FYM), vermicompost, and green manures into the soil can also help improve soil health. Additionally, the use of lightweight machinery in the fields can reduce soil compaction and minimize damage to soil structure.

From Waste to Wealth: Exploring the Various Uses of Paddy Straw

The paddy straw produced from paddy fields can be utilized in various activities that promote proper waste management and help reduce GHG emissions. Paddy straw can be used in mushroom cultivation as a base material for preparing mushroom bags or beds. After harvesting the mushrooms, the straw can be further used for compost preparation. Additionally, paddy straw can be processed into bales and briquettes, which can be used as an alternative fuel source. The pulp from the straw can be used in the manufacturing of paper and various cutlery items.

Conclusion

The issues mentioned above are serious but not impossible to solve. By combining Integrated Nutrient Management (INM), proper land use, efficient resource utilization, and effective waste management, these problems can be addressed. Paddy is a major crop in Odisha, supporting and feeding a large portion of the population. Therefore these issues need to be recognized and appropriate actions must be taken for the welfare of the farmers, the environment and the people of Odisha.

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Designing Pollinator-Friendly Landscapes: Enhancing Biodiversity

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Pollinator populations are in decline due to habitat loss, pesticide use and climate change, which poses a threat to biodiversity and ecosystem health. When we design urban landscapes thoughtfully, they can serve as vital habitats and support for pollinators such as bees, butterflies and birds. This paper explores the principles of designing pollinator-friendly landscapes, emphasizing the use of native plant species, diverse flowering seasons and habitat features that meet the needs of pollinators. By reviewing current literature on urban biodiversity and pollinator ecology, this study identifies key elements that enhance pollinator populations in cities and proposes a framework for creating sustainable, biodiverse urban spaces. The findings demonstrate that pollinator-friendly landscaping not only enhances aesthetic value but also plays a critical role in biodiversity conservation. These insights have significant implications for urban planners and landscape architects seeking to create resilient, ecologically sound environments.

Introduction

The art and science of modifying the visible features of an area of land that involves creating a harmonious blend of natural and man-made elements is called landscaping. Landscaping aims to enhance aesthetic appeal, functionality and biodiversity. Transforming our gardens into vibrant ecosystems that support a diverse range of pollinators is not only aesthetically pleasing but also critical for biodiversity and the health of our planet. Pollinators such as bees, butterflies, hummingbirds and bats play a vital role in transferring pollen between plants, supporting the reproductive success of countless plant species. However, these essential pollinators face challenges such as habitat loss due to pesticide use and climate change, leading to declining populations. The composition and management of urban green spaces, including parks, gardens and even green roofs, can have a significant impact on the abundance and diversity of pollinator communities. Beyond the specific features of individual green spaces, the overall landscape configuration and connectivity of habitats within the city can also influence pollinator communities. Pollinators may move between different green spaces to access resources and the proximity and accessibility of these areas can determine the success of their populations. Designing a pollinator-friendly landscape involves incorporating elements that attract and sustain pollinators. This can include planting nectar-rich flowers, providing nesting sites and shelters, minimizing pesticide use and creating a diverse range of plant species to support pollinators throughout the year. By following these principles, we can create not just visually stunning landscapes, but also ecosystems that are full of life and contribute to the conservation of vital pollinator species.

Which pollinators need to increase in cities

The "Pollinator" is a large group of organisms defined by their function. However, bees and butterflies may be the most well-known pollinators, a range of taxonomic categories including not only wasps and other members of the Apoidea superfamily

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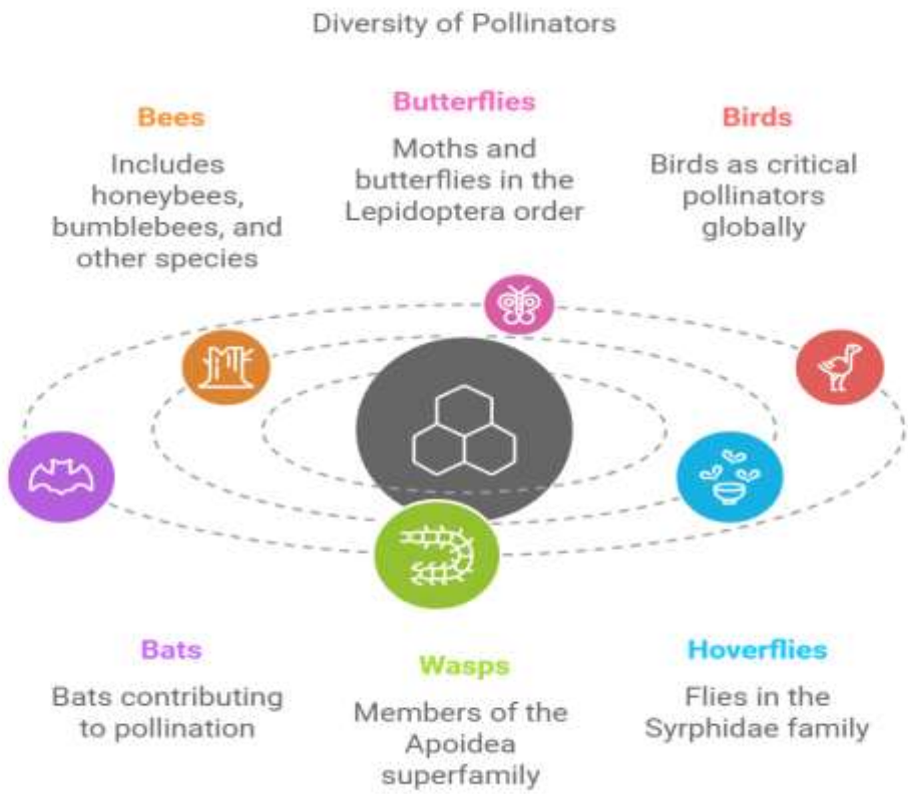
but also moths, which make up nearly 90% of species in the Lepidoptera order, as well as "hoverflies" in the Syrphidae family of the Diptera order (true flies). The term "bee" is generally applied to a diversity of species within the Anthophila clade and includes not only honeybees and bumblebees but also mason, carpenter and sweat bees. Birds and bats are also critical pollinators in many parts of the world, though insects remain the most frequently recorded pollinators in urban areas worldwide. Specifically, across studies of urban areas globally, Hymenoptera, especially honeybees and bumblebees, are the most frequently recorded insects, followed by Lepidoptera and Diptera.



Key elements of pollinator-friendly landscapes

Plant selection: When selecting plants for your garden, it's important to choose native species that can thrive in your local climate and soil conditions.

- *Native plants*: Native plants are particularly beneficial because they are well-suited to support local pollinators. Additionally, consider including a diverse array of plants that bloom at different times throughout the year. This ensures a continuous supply of nectar and pollen for pollinators.
- *Variety*: Aim for various species that bloom in each season - Winter, summer and rainy. Lastly, when choosing plants, opt for a mix of flower shapes and colours.
- *Different shapes and colours*: Pollinators are attracted to a range of shapes and colours, so incorporating tubular, flat and clustered flowers in blue, purple, yellow and white hues can help to attract and support local pollinators.

Habitat features for pollinators: When creating habitats for pollinators, it's essential to provide specific features to ensure their well-being and survival.

- *Nesting sites*: Nesting sites can be established by implementing favourable surroundings and environment like honey bees (*Apis mellifera*) prefer cavities in trees or rock formations, while solitary bees and bumble bees may nest in pre-existing hollow stems, snail shells, or dig burrows in the ground.
- *Water sources*: Clean water sources are crucial and can be made available through bird baths, shallow dishes or small ponds.
- *Shelter*: It's important to incorporate shrubs, tall grasses and trees to offer ample shelter from predators and harsh weather conditions. These features contribute to creating a thriving ecosystem for pollinators and help support their populations.

Maintenance practices:

Prioritize pollinator safety and continuous food sources

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- *Avoid pesticides*: Avoid or minimize the use of pesticides option for organic pest control methods or integrated pest management practices. Pesticides harm pollinators directly.
- *Minimize herbicide use*: Consider hand-pulling weeds or using organic alternatives. Herbicides can contaminate nectar and pollen.
- *Avoid excessive pruning*: Prune plants judiciously to avoid disturbing nesting sites and food sources.

Manage water resources

- *Provide a shallow water source*: A birdbath or pond can offer a vital water source. Avoid stagnant water this can breed mosquitoes. Provide water deeply to encourage deep root growth, which is beneficial for plants and soil health.
- *Mulching*: Use mulch to retain soil moisture and reduce weeds, but leave some bare patches for ground-nesting bees.
- Keep an eye on pollinator activity to identify any potential issues.

Landscape design:

- *Layering*: Create layers in your garden with trees, shrubs, perennials and groundcovers to offer diverse habitats.
- *Connectivity*: Design corridors of native plants to connect different habitats and allow pollinators to move freely across the landscape.
- *Buffer zones*: Establish buffer zones with native vegetation around gardens to protect them from pesticide drift and pollution.

Specific plant recommendations

Bees	Butterflies	Humming birds
Crocus ✓ Lavender ✓ Goldenrod ✓ Aster ✓ Sedum ✓ Marigold ✓ Sunflower ✓ Hibiscus ✓ Lantana ✓ Jamine ✓ Tulsi ✓ Crotalaria	*Larval host plants*: ✓ Milkweed (monarchs) ✓ Parsley (swallowtails) ✓ Violets (fritillaries) *Nectar plants*: ✓ Butterfly Bush ✓ Lantana ✓ Arali (Indian coral tree) ✓ Curry leaf ✓ Golden shower ✓ Balsam ✓ Cosmos ✓ Marigold ✓ Periwinkle ✓ Ixora	✓ Trumpet honeysuckle ✓ Beebalm ✓ Scarlet sage ✓ Cardinal flower ✓ Erythrina variegata ✓ Phlox ✓ Certain orchids ✓ Petunia

Implementation steps

Creating a thriving pollinator habitat in your landscape involves several key steps:

- Assess your site: Begin by thoroughly evaluating the current conditions of your landscape. Take into account the soil type, amount of sunlight and the existing vegetation. This will help you understand the unique characteristics of your landscape and inform your planting decisions.
- Plan your design: Create a detailed layout that incorporates the key elements necessary for a thriving pollinator habitat. Consider the specific plant recommendations that are most suitable for your landscape, taking into

account factors such as seasonal bloom times and plant heights. This thorough planning will ensure that your pollinator habitat is both beautiful and functional.

- Prepare the soil: Enhance the health of your soil by adding nutrient-rich compost and ensuring that it has proper drainage. Healthy soil is crucial for supporting the growth of diverse plant species and creating an environment that is attractive to pollinators.
- Planting: When planting, consider arranging your plants in clusters to make it easier for pollinators to locate flowers. Be sure to water new plants regularly, especially during the establishment phase, to promote healthy growth.
- Ongoing care: After planting, it's important to monitor the health of your plants and manage any weeds that may compete with them. Additionally, be prepared to adjust your planting as necessary to ensure that your pollinator habitat continues to thrive over time. Regular maintenance is key to sustaining a vibrant and diverse ecosystem that supports pollinators.

Conclusion

Creating a pollinator-friendly landscape is a wonderful way to support biodiversity. Designing and maintaining landscapes with pollinator safety is our responsibility. We can surely significantly contribute to the conservation of these vital species, ecology and enhance the overall biodiversity of our environments.

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