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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 01

BEE BEHAVIOUR AND ITS COMMUNICATION

Introduction

Honey bees are far more than producers of honey and wax; they are master communicators. To sustain their hive, foragers have evolved a sophisticated "dance language" to encode precise navigational details about distant resources. This behaviour, first decoded by Nobel laureate Karl von Frisch and later found to include acoustic signals, stands as one of the most intricate non-human communication systems known to science, offering profound insights into animal behaviour, social cooperation, and the evolution of symbolic language**.**

Bee Behaviour :

Swarming:

Swarming is the reproductive process in which a substantial part of a honeybee colony, led by the old queen, leaves its hive to found a new one. Overcrowding, usually from rapid population growth, is the primary trigger. To prepare, workers build special cells to rear new queens. A swarm includes the old queen, many workers, and some drones, and usually occurs after the main nectar flow in late spring or early summer.

1. **Instinct and Preparation:** Large, healthy colonies develop the natural instinct to swarm in order to reproduce.
2. **Scouting:** Prior to swarming, scout bees begin searching the environment for a suitable new nesting site.
3. **Departure:** Once new queen cells in the original hive are sealed for pupation, the existing queen departs. On a clear morning, she leads approximately one-third to one-half of the colony's workforce out of the hive.
4. **Initial Cluster:** The swarm initially settles on a nearby object, such as a tree branch, forming a dense, temporary cluster.
5. **Final Migration:** After scouts have finalized the location of the new nest site, the entire cluster flies to establish the new colony.

Emergency Release of Queen

In the event of the queen's death, the colony undertakes an **emergency queen replacement**. Worker bees select eggs or very young larvae (one to two days old) that are already present in worker cells. They then modify these cells, enlarging and reshaping them into the distinctive, downward-hanging queen cells.

The chosen larva is fed copious amounts of royal jelly, triggering its development into a new queen rather than a worker.

Multiple emergency queen cells are typically constructed, often positioned in the central area of the comb for protection. The first new queen to emerge will immediately seek out the other queen cells, using her stinger to eliminate the remaining rival queens—whether they are still developing or ready to emerge. Once she has secured her position, the virgin queen leaves the hive for her mating flights. After successfully mating, she returns to the colony as the new, fully fertile queen, capable of laying both fertilized eggs (which become workers or new queens) and unfertilized eggs (which become drones).

Worker Policing and Reproductive Suppression

When a queen is lost and the colony lacks young brood suitable for queen rearing, a different reproductive pathway may emerge. Some worker bees develop active ovaries and begin laying unfertile eggs, which can only develop into drones. This usually occurs in prolonged queenless conditions, often termed a "laying worker" situation.

However, such colonies rarely thrive, as these events also trigger a mechanism known as "worker policing"—in which other workers identify and destroy worker-laid eggs to preserve colony genetic integrity. Laying workers also lay multiple eggs per cell, creating competition among eggs and further reducing colony productivity. Without a queen or young larvae to raise a new one, the colony ultimately declines.

Division of Labor in a Honeybee Colony

Each bee has an age-based job vital to the hive. The queen uses pheromones to keep order, control reproduction, and maintain colony unity.

Blossom Faithfulness

Bees focus on one type of flower until its pollen and nectar run out, then move to another.

Natural Queen Replacement (Supersedure)

Supersedure is a process by which honeybees naturally replace an aging or underperforming queen without swarming or human intervention. This ensures the colony's long-term survival and reproductive health. It typically occurs during active seasons—spring, summer, or early autumn.

When the old queen's egg-laying declines—often producing fewer fertilized eggs—worker bees construct one or a few queen cells, usually in the center or lower area of the comb. After the new queen emerges and mates, she takes over, and the old queen is gradually phased out.

Beekeepers are generally advised not to intervene, as the colony is best equipped to manage its own queen succession. This natural replacement helps maintain colony strength and continuity.

Bees Communication

While many animals rely on body language, eye contact, or vocal calls, honey bees communicate through an extraordinary combination of movement and chemical signals.

Two primary methods form the basis of their interactions:

1. **Movement**
   Bees perform precise movements like the well-known "waggle dance" to share detailed information about the distance and direction of food sources.
2. **Odor & Chemical Signals**
   Using pheromones and scents, they convey messages about colony health, reproduction, and threats, helping maintain hive harmony and organization.

These instinctive, non-verbal communication methods allow bees to share vital information on resources, navigation, and colony needs with remarkable accuracy.

Different types of Bees

Queen: There is only one queen per hive. Her main job is to lay eggs and produce pheromones that keep the colony united. She lives 1–2 years.

Worker: These are all the other female bees. They perform every task in the hive: cleaning cells, nursing larvae, building comb, guarding the entrance, and collecting food. Workers live about 5–7 weeks during active seasons.

Drone: Drones are the male bees. Their only purpose is to mate with a virgin queen from another colony. After mating, they die. Drones that don't mate are expelled from the hive before winter to conserve resources.

How Honeybees Find Flowers

Bees see differently than humans. They can't see red well, but they can see ultraviolet (UV) light. Flowers often have ultraviolet patterns that act like guides, showing bees where to find nectar and pollen quickly. This helps them work faster and share food locations with the hive

Communication process in Bees are :

Touch

Bees use touch to communicate and sense their environment. They identify nestmates by touching antennae and taste objects with their tongues. Their sensitive antennae and feet help measure comb cells to build perfect honeycombs. Tiny hairs covering their bodies detect vibrations and touch, alerting them to danger.

Dance Language

After finding food or water, a forager returns to the hive and performs a dance to share the location. The most famous is the waggle dance, used for distant sources. Bees dance in the dark, using precise movements to indicate direction and distance—like a living navigation system.

Round Dance

For food sources within about 50 meters, bees perform a round dance. They move in tight circles, sometimes adding a small waggle to indicate the quality of the flowers. This simple movement tells others that food is nearby.

Waggle Dance

For more distant food sources, bees perform the waggle dance in a figure-eight pattern. The duration and angle of the waggle indicate distance and direction relative to the sun. Multiple bees may share different finds, and the hive "votes" by following the most enthusiastic dancer, ensuring the colony chooses the best site.

Vibration & Sound

Vibration and sound are crucial in bee communication, especially for solitary species:

- Females use buzzing vibrations to attract males.
- Males produce soft buzzes during mating.
- Colonies create a collective, warning buzz in response to threats.
- Loud buzzing near the nest signals danger or agitation.

Odor & Pheromones

Bees use chemical signals called pheromones to communicate within the colony. Different pheromones trigger different responses . Bumblebees use scent instead of dance—they fan their wings to spread flower odors, guiding others to nearby food. This method is less precise than dances but effectively indicates a nearby food source.

Conclusion

Bees are fascinating creatures, and our understanding of them grows daily. Central to this understanding is their dance language—a precise system for communicating the location and value of food sources. While more research is needed to fully decode its complexity, this unique behavior remains their primary method for sharing essential data on a source's quality, profitability, and abundance.

For beekeepers, comprehending this communication is crucial. It not only makes the beekeeping experience more successful and rewarding but also helps ensure the safety and well-being of both the keeper and the hive. Ultimately, such knowledge transforms simple interest into informed practice, guiding anyone inspired by bees toward a deeper and more fulfilling connection with these remarkable insects.

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Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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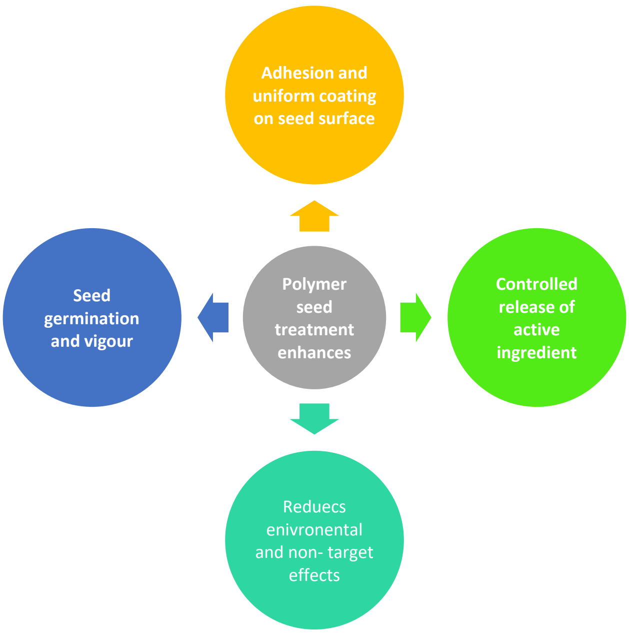
ARTICLE ID: 02

IMPACT OF POLYMER SEED TREATMENT: A SUSTAINABLE APPROACH FOR BETTER CROP ESTABLISHMENT

Introduction:

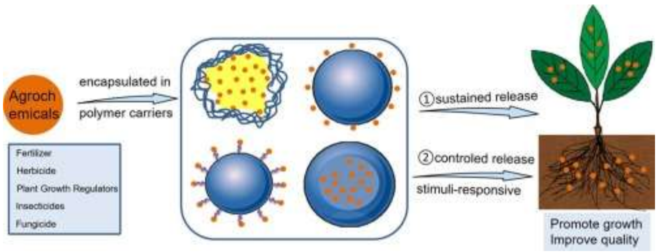
Polymers are biodegradable, and environmentally friendly that have found in wide range of applications in modern agriculture. With the increasing need for sustainable crop production and reduced dependence on excessive chemicals, recently polymer based technologies have emerged as innovative tools for improving seed quality, crop establishment and disease management. Seed treatment with polymers act as a carriers, protectants and regulators, enabiling the targeted and efficient delivery of agrochemicals to seeds and seedlings. Among various polymers, amphiphilic block copolymers have gained a special attention due to their unique hydrophilic and hydrophobic part, which are covalently linked with in the same molecule, they have ability to form as a nano-structures thus make them useful in agricultural applications especially in crop protection. The amphiphilic co polymers that are self assembled that contains agrochemicals as fungicides, chemicals etc., such controlled or sustained release ensures prolonged protection of seeds and young seedlings especially during critical stages of germination and early growth (Majumder *et al.*, 2020).



Benefits of nano-polymer seed treatments

The self assembled polymers minimizes rapid loss of chemicals through leaching, volatalization, and also they have lower critical micelle concentration, high collodial stability, biocompatability, non-toxicty, biodegradability, photo degradation or microbial break down, and it reduces the total chemical required for crop protection by providing the minimal amount of chemical making polymer based seed treatment as both economical and environmentally safer. Among amphiphilic polymers, polyethylene glycol based amphiphilic polymers are widely used to provide controlled release of agrochemicals as mancozeb and thiamethoxam, that leads to improved disease and pest control and also enhance seed germination as the active ingredient on the seed coat promotes enhancement of seed quality parameters (Sarkar *et al*., 2023).

In seed technology, polymer based seed treatments have significantly improved traditional seed treatment practices. As conventional seed treatments often suffer from uneven coating, poor adhesion of chemicals, dust formation and loss of chemical after sowing, the polymer coating overcomes all these limitations by forming a thin layer around the seed (Sarkar *et al*., 2012). This coating not only improves retention of chemical but also protects them from premature loss during handling, storage and also enhances improved germination, seedling vigor and uniform crop establishment. The PEG based polymers enhances the efficiency of seed treatment by improving the penetration and availability of chemicals as the nano-carriers ensures the active ingredient remains in close proximity to the seed and roots providing better protection against soil-borne pathogens during most vulnerable stages of crop growth. In addition they also induce host resistance by activating antioxidant enzymes, enhancing stress responsive pathways and improving health of seedlings (Majumder *et al.*, 2022).



(Adak *et al*., 2012)

Seed treatment with thiram based polymer had a beneficial role in maintaining seed germination during storage and promotes controlled release of formulation by enhancing germination, as it acts as a protective barrier, from excess moisture, oxygen and storage fungi. Polymer coating also enhances seed vigour which reflects the potential and uniform seedling emergence, the improvement is due to maintaining environment within seed and protecting the seed against microbes as nano-range amphiphilic polymers, due to their **large surface area**, form a uniform and continuous coating over the seed surface. This uniform coverage reduces metabolic stress, minimizes oxidative damage, and slows down the biochemical processes associated with seed ageing. Consequently, polymer-coated seeds produce stronger, healthier seedlings with better establishment potential (Kumar *et al*., 2010).

Control of storage fungi and seed health:

Fungal infestation is one of the major causes of seed deterioration during storage. Several storage fungi, including *Aspergillus*, *Alternaria*, *Fusarium*, and *Penicillium* species, are commonly associated with reduced seed quality. Among these, *Aspergillus niger* is particularly destructive in oil-rich seeds such as soybean.

Polymer-based CR formulations of thiram were highly effective in suppressing fungal growth during storage. While uncoated seeds showed a rapid increase in fungal infection over time, polymer-coated seeds recorded significantly lower levels of infection even after six months. The fungicide encapsulated within the polymer matrix was released slowly, providing prolonged protection and preventing further proliferation of storage fungi.

Conclusion:

Polymer-based seed coating technology, particularly using **nano-range amphiphilic polymers**, represents a major advancement in seed science and crop protection. By slowing seed ageing, enhancing germination and vigour, and controlling storage fungi, these polymers significantly improve seed quality and crop establishment. Their ability to deliver agrochemicals in a controlled and targeted manner aligns well with the principles of **precision and sustainable agriculture**. As research continues to expand, polymer-based seed treatments are expected to play a crucial role in ensuring seed longevity, crop productivity, and food security.

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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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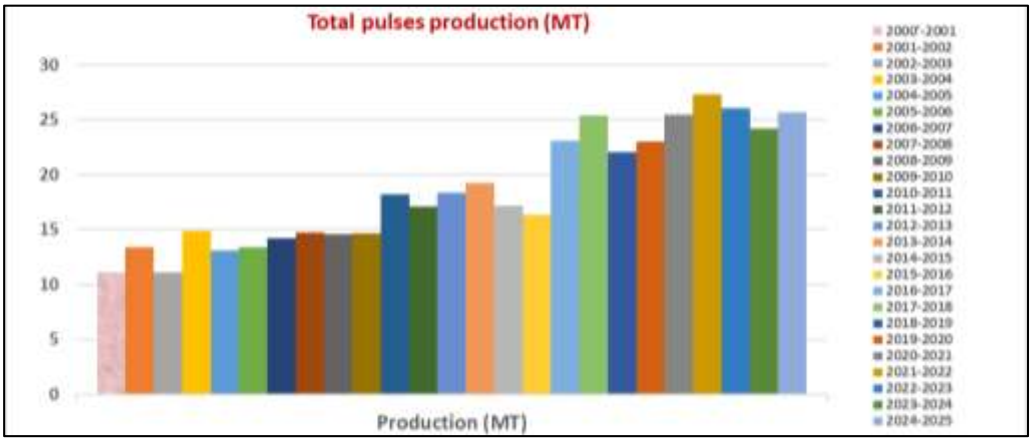
ARTICLE ID: 03

CLIMATE-RESILIENT PULSES: SECURING INDIA'S PROTEIN NEEDS IN A CHANGING CLIMATE

Introduction: Pulses, The Protein Backbone of Indian Diets

Pulses are leguminous crops cultivated primarily for their dry edible grains. The Food and Agriculture Organization (FAO) recognizes ten major and five minor pulse crops. Globally, more than a dozen pulse species is grown across 105 countries, where they form an integral component of diverse cropping systems. Pulses play a crucial role in enhancing the sustainability of cereal-based agriculture through biological nitrogen fixation, soil health improvement, and diversification of production systems. In predominantly vegetarian countries such as India, pulses are indispensable for ensuring food and nutritional security due to their high protein content and essential micronutrients. Pulses such as chickpea, pigeonpea, lentil, mungbean and blackgram are central to Indian agriculture and nutrition. They provide 20–25% high-quality protein along with essential micronutrients like iron, zinc and folate, making them indispensable for a predominantly vegetarian population. Beyond nutrition, pulses enhance soil fertility by fixing 50–150 kg nitrogen per hectare through symbiotic root nodules, thereby reducing fertilizer requirements and improving the sustainability of cereal-based cropping systems... remove redundancy.



Climate Change: A Growing Threat to Pulse Production

Pulse production in India is increasingly vulnerable to climate change. Projections indicate a rise in mean temperature of about 1.7°C during the *kharif* season and up to 3.2°C during the *rabi* season by 2070 (IPCC, 2023).

In parallel, per capita water availability has declined from over 6042 m³ during the post-independence period and is projected to drop to 1140 m³ by 2050, signalling chronic water stress. As pulses are largely grown under rainfed conditions, rising temperatures, erratic rainfall and water scarcity pose serious risks to productivity.

Abiotic Stresses Limiting Pulse Yields

Abiotic stresses are the major causes of yield instability in pulse crops. Drought stress in chickpea, pigeonpea, lentil and mungbean reduces flowering, pod set and seed filling. Heat stress during reproductive stages leads to pollen sterility and flower drop in chickpea, lentil and blackgram. Waterlogging damages roots and disrupts oxygen supply in pigeonpea, mungbean and blackgram, while salinity impairs nodulation and nutrient uptake in chickpea and lentil. These stresses can cause yield losses ranging from 10 to 40 per cent under severe conditions.

Why Conventional Breeding Alone Is Not Enough

Despite sustained breeding efforts using conventional approaches, significant genetic gains in pulse productivity have remained elusive. In India alone, over 1074 improved pulse varieties were released between 1969 and 2022, yet yield improvements have been marginal (GOI, 2022). A key constraint is the strong genotype × environment interaction, which limits the stability of yield across locations and seasons. Moreover, tolerance to abiotic stresses is controlled by multiple genes and complex physiological traits, making progress through conventional breeding slow.

Genomics-Assisted Breeding: A New Hope

Modern breeding approaches integrating genomics with conventional methods are reshaping pulse improvement. Molecular markers, QTL mapping and genomic selection enable precise identification of stress-tolerant genotypes. For example, drought-tolerance QTL hotspots identified in chickpea have been successfully introgressed into elite varieties, resulting in yield advantages of 15–20% under rainfed conditions. Such genomics-assisted breeding approaches shorten breeding cycles while maintaining grain quality.

Climate-Resilient Pulses for Nutrition and Farmers' Livelihoods

India's per capita pulse availability is about 42 g per day, well below the ICMR recommendation of 52 g per day. Bridging this gap requires raising national pulse production from the current 25.68 million tonnes to over 32 million tonnes (Indiastat, 2026). Climate-resilient pulse varieties, combined with improved agronomic practices and efficient water management, can stabilize yields, reduce crop failure risks and improve farmers' incomes, particularly in rainfed and marginal regions.

Pulses for People and Planet

Beyond food security, climate-resilient pulses contribute to environmental sustainability. By reducing fertilizer use, improving soil health and lowering greenhouse gas emissions, pulses support climate-smart agriculture. Strengthening pulse research, accelerating the adoption of stress-tolerant varieties and supporting farmers through policy interventions can transform pulses from climate-vulnerable crops into key allies for sustainable food systems.

Conclusion: Building a Climate-Smart Future with Pulses

Pulses lie at the intersection of nutrition, sustainability and climate resilience. Investing in climate-resilient pulse varieties through advanced breeding technologies, effective extension and farmer-friendly policies is essential for securing India's protein needs in a warming world. With focused efforts, pulses can play a decisive role in ensuring food security, environmental health and resilient livelihoods.

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Just Agriculture Multidisciplinary *e- newsletter*

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

ARTICLE ID: 04

CROP RESIDUE MANAGEMENT FOR SUSTAINABLE AGRICULTURE

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Abstract

India generates approximately 500 million tons (MT) of crop residues annually, a significant portion of which is burned in situ, leading to severe environmental degradation, soil nutrient depletion, and public health crises. This comprehensive study reviews the state of crop residue management (CRM) in India, analyzing the shift from traditional burning to sustainable alternatives. We evaluate in-situ and ex-situ management strategies, including livestock feed utilization, composting, mulching, and thermochemical conversion into energy (biochar, biogas, and briquettes). Special emphasis is placed on the mechanization of residue management (e.g., Happy Seeder, Super Seeder) and the impact of these practices on soil physicochemical and biological properties. The study concludes that adopting integrated CRM strategies can restore soil health, mitigate greenhouse gas (GHG) emissions, and provide economic resilience to farmers.

❖ Introduction

Modern agriculture in India has achieved self-sufficiency in food production, yet it faces the colossal challenge of managing agricultural waste. India generates a surplus of 141 MT of crop residue annually, of which 92 MT is burned due to a lack of sustainable management solutions and the narrow window between harvesting and sowing subsequent crops.

The "Green Revolution" increased cropping intensity and grain production to 316.06 MT (2021-22), but simultaneously escalated residue generation. While crop residues are nutrient-rich resources containing organic carbon (C) and essential macronutrients (N, P, K, S), their burning results in the permanent loss of these assets and the emission of toxic pollutants like particulate matter (PM), CO, and CH_4. This review explores holistic management approaches to convert this "waste" into "wealth."

❖ The Crisis of Crop Residue Burning

Burning crop residue is the most time-efficient but environmentally damaging method of disposal. The practice is most prevalent in North-Western India, particularly with rice (43%), wheat (21%), and sugarcane (19%) residues.

- **Nutrient Loss and Soil Degradation**

Burning does not merely clear the field; it sterilizes the topsoil. The National Policy for Management of Crop Residues reports that burning 1 ton of stubble results in the loss of:

Nitrogen: 5.5 kg
Phosphorus: 2.3 kg
Potassium: 25 kg
Sulphur: 1.2 kg
Organic Carbon: Complete loss (100%).

Furthermore, the heat from burning (raising soil temperature to 35.8–42.2°C at 10 mm depth) kills beneficial soil microflora and fauna, reducing bacterial populations by over 50%.


- **Environmental and Health Impact**

The atmospheric consequences are dire. Burning releases 70% of the carbon in rice straw as CO_2, along with 7% as CO and 0.66% as CH_4. These emissions contribute significantly to the formation of smog, aerosols, and fine particulate matter (PM2.5), which can penetrate the human bloodstream, causing chronic respiratory and cardiovascular diseases.

❖ **<u>Sustainable Strategies for Crop Residue Management</u>**

To mitigate these impacts, various in-situ (on-field) and ex-situ (off-field) strategies have been developed.

- **Livestock Feed**

Conventionally, crop residues are used as fodder. However, rice straw is often considered poor feed due to its high silica content (~8%) and low protein.

Challenges: High silica, low palatability, and high oxalate concentration can cause health issues like "Degnala" disease in cattle.

Solutions: Treatment with ligninolytic fungi or mixing with protein-rich supplements (e.g., legume residues, broccoli byproducts) can enhance digestibility and nutritional value.

- **In-situ Residue Retention and Incorporation**

Retaining residues in the field is critical for conservation agriculture.

- ✓ **Soil Physical Improvements:** Residue retention increases water infiltration by 20.6%, reduces bulk density by 6%, and improves aggregate stability. It acts as a physical barrier, reducing soil erosion by wind and water.
- ✓ **Chemical Improvements:** Incorporation increases Soil Organic Carbon (SOC) by 18–44%. However, cereal residues with high C:N ratios (70–100:1) can cause temporary nitrogen immobilization. To counter this, farmers are advised to apply an additional 20–40 kg N/ha or incorporate residues 10–40 days before sowing.
- ✓ **Biological Improvements:** Residue retention enhances microbial biomass by 90–95% and earthworm populations by 30%, creating a thriving ecosystem for nutrient cycling.

- **Composting**

Composting transforms recalcitrant straw into nutrient-rich fertilizer.

- ✓ **Vermicomposting:** Uses earthworms to breakdown residues. It combines anaerobic (40–45 days) and aerobic phases to normalize the C:N ratio.
- ✓ **Microbial Enriched Compost:** Studies utilizing effective microorganisms (EM) with rice straw have shown significantly higher N, P, and K contents compared to untreated compost. Utilizing rock phosphate during composting can further enrich the product to contain 2.3% P.

- **Energy Generation:** Thermochemical and Biochemical Transformation

Converting residue into energy offers a dual benefit:

fossil fuel displacement and waste reduction.

- ✓ **Gasification**

Gasification heats biomass to 500–1400°C with limited oxygen to produce "producer gas" or "syngas" ($CO + H_2$).

Efficiency: The process has a conversion efficiency of 0.5–0.8 and is suitable for generating electricity (<2 MW plants). However, tar formation remains a technical challenge, often requiring catalysts like $Ca(OH)_2$ for purification.

- ✓ **Biogas and Bio-ethanol**

Anaerobic Digestion: Converts wet biomass (up to 90% moisture) into biogas (60–70% CH_4). India has the potential to produce 172 billion m^3 of biogas annually from crop residues. Pre-treatment of straw (e.g., heating to 110°C with 2% ammonium solution) can boost gas production by 17.5%.

Bio-ethanol: Biochemical fermentation of lignocellulosic residues can produce ethanol, with India currently producing over 51 billion liters annually.

- **Biomass Briquetting**

Briquetting involves densifying loose straw into solid blocks using high pressure, which raises the temperature to 170–200°C and melts the lignin (natural binder).

Advantages: Briquettes have high calorific value and bulk density (1221 \ kg/m^3), making them easier to transport and store. They can replace coal in boilers and brick kilns, significantly reducing SOx and NOx emissions compared to loose straw burning.

- **Mulching**

Applying residues as surface mulch regulates soil temperature (reducing fluctuations), minimizes evaporation (saving 14–29% irrigation water), and suppresses weeds. In semi-arid regions, mulching has been shown to reduce sediment loss and runoff effectively.

❖ <u>**Mechanization: The Backbone of Residue Management**</u>

Several advanced machines have been developed to facilitate in-situ management without the need for burning.

- **Happy Seeder**

A tractor-mounted machine that cuts and lifts paddy straw, sows wheat into the bare soil, and deposits the straw over the sown area as mulch.

<u>Benefits:</u> Combines sowing and mulching in a single pass. It improves germination, conserves moisture, and saves Rs. 1500–2000 per hectare compared to conventional tillage.

<u>Capacity:</u> 0.6–0.75 acres/hour with a 45 HP tractor.

- **Super Seeder**

An advancement over the Happy Seeder, the Super Seeder incorporates the straw into the soil using a rotary unit while simultaneously sowing seeds.

<u>Mechanism:</u> It offers complete residue incorporation, preventing the "clogging" issues sometimes faced with loose straw.

<u>Capacity:</u> 0.35 ha/hour with a 50 HP tractor.

- **Rotary Disc Drill**

Designed for conservation agriculture, this machine uses powered discs to cut through residue and place seeds with minimal soil disturbance. It is highly effective for sowing in thick residues of sugarcane or rice.

- **Straw Balers**

For ex-situ management, balers compress loose straw into rectangular or round bales (15–35 kg) for transport to power plants or paper mills. Using balers can reduce gaseous emissions by 45-fold compared to burning.

❖ <u>**Government Initiatives and Policy Framework**</u>

The Government of India has launched aggressive schemes to curb residue burning:

- ✓ **Subsidies:** Policies like the "Promotion of Agricultural Mechanization for In-Situ Management of Crop Residue" provide 50–80% subsidies for purchasing machinery like Happy Seeders, Super Seeders, and Balers.
- ✓ **NTPC Co-firing:** The National Thermal Power Corporation (NTPC) has been mandated to use 10% biomass briquettes in

coal plants, creating a market for crop residues at approximately Rs. 5500 per ton.

- ✓ **Regulatory Acts:** Strict enforcement under the Air (Prevention and Control of Pollution) Act, 1981, and National Green Tribunal directives aim to penalize burning.

❖ Conclusion and Future Thrust

Crop residue is not waste; it is a vital resource for sustainable agriculture. The transition from burning to management requires a multi-pronged approach:

- ✓ ***Adoption of In-situ Technologies:*** Widespread use of Happy Seeders and Super Seeders to retain nutrients in the soil.
- ✓ ***Bio-energy Integration:*** Scaling up biochar, biogas, and briquetting facilities to create a value chain for farmers.
- ✓ ***Custom Hiring Centers:*** Promoting rental models for expensive machinery to make them accessible to small and marginal farmers.

By integrating these strategies, India can simultaneously achieve food security, energy independence, and environmental restoration.

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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

ARTICLE ID: 05

GLOBAL RECOGNITION OF BIOCHAR

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Abstract

Biochar has emerged as a globally recognized climate-smart technology due to its dual role in climate change mitigation and enhancement of soil health. Derived from the pyrolysis of biomass under oxygen-limited conditions, biochar is characterized by its high carbon stability, enabling long-term carbon sequestration in soils and contributing to the reduction of atmospheric greenhouse gas concentrations. Globally, biochar application has been shown to improve key soil health indicators, including soil organic carbon, nutrient retention, water-holding capacity, aggregation, and microbial activity, thereby increasing agricultural resilience to climate-induced stresses such as drought and nutrient depletion. International research initiatives and policy frameworks increasingly acknowledge biochar as a nature-based solution that supports climate adaptation and mitigation strategies while promoting sustainable land management. Its integration into climate-smart agriculture, regenerative farming systems, and circular bio economy models aligns with global efforts to achieve the Sustainable Development Goals related to climate action, food security, and land degradation neutrality. Despite challenges associated with feedstock variability, standardization, and large-scale adoption, the growing body of scientific evidence underscores biochar's global recognition as a promising tool for improving soil health and addressing climate change.

Keywords : Biochar, climate change, Soil improvement

Introduction

Biochar can act as a soil conditioner enhancing plant growth by supplying and retaining nutrients and by providing other services such as improving soil physical and biological properties. In part of Asia, notably Japan and Korea, the use of biochar in agriculture also has a long history. The use of biochar to "tie up" carbon has the potential to reduce current global carbon emissions by as much as 10 per cent. Climate change, soil degradation, soil contamination, scarcity of water, and food security pose serious risks to the environment and civilization (Alkharabsheh et al., 2021). Biochar is a versatile and sustainable tool for agricultural and environmental.

However, the overall composition and characteristics of biochar depend on the choice of feedstock and the production process (Wang et al., 2020). This article explores the evolution of biochar's global status, examines its scientific foundations, highlights how international institutions and markets are adopting biochar, and discusses future pathways for broader acceptance and implementation. It is anticipated to assist scientists and farmers in creating and choosing appropriate biochar technologies to improve agriculture and environmental sustainability without compromising crop productivity.

Global Acknowledgment of Biochar and Studies Pertaining To It

Scientific interest in biochar intensified following the recognition of *Terra Preta* soils of the Amazon, which demonstrated long-term soil fertility linked to charred organic materials (Lehmann et al., 2003). International research organizations, including the International Biochar Initiative (IBI) and national agricultural research systems, have highlighted biochar as a nature-based solution capable of enhancing soil organic carbon, nutrient retention, and water-holding capacity while simultaneously sequestering carbon in stable forms (IBI, 2021).

Kimetu et al. (2008) investigated the use of biochar to mitigate soil degradation. Comparing the yields of maize grown in Kenyan soils over a degradation gradient. In the severely deteriorated soils, the use of biochar doubled the yield of maize grain from roughly 3 to 6 t/ha. In Colombia, Rondon et al. (2007) investigated how adding charcoal to common beans improved their biological N2 fixation (BNF). He discovered that, in comparison to the control, bean yield rose by 46% and biomass generation by 39% at 90 and 60 g biochar/kg, respectively.

Lehmann et al. (2003) investigated nitrogen retention and soil fertility. In Brazil, he planted rice crops in lysimeters and cowpeas in pots. He discovered that adding biochar greatly enhanced biomass output by 38 to 45% (no yield recorded). In 1985, Kishimoto and Sugiura conducted research on soybeans grown on volcanic ash loam in Japan. He found that Char boosted yield by 151% at 0.5 t/ha, decreased yield by 63% at 5 t/ha, and decreased yield by 29% at 15 t/ha. He also identified that at 0.5 t/ha, wood charcoal, bark charcoal, and activated charcoal increased biomass by 249, 324, and 244%, respectively.

In comparison to unamended soils, the addition of biochar (5% w/w) to the soil enhanced the sorption of atrazine and acetochlor, leading to lower dissipation rates of herbicides. Furthermore, the Intergovernmental Panel on Climate Change (IPCC) has acknowledged biochar as a promising carbon dioxide removal option under land-based mitigation strategies, emphasizing its potential for long-term carbon storage and co-benefits for soil health (IPCC, 2019). Despite challenges related to feedstock variability, economic feasibility, and standardization, the growing body of global scientific evidence underscores biochar's recognition as a viable tool for sustainable land management and climate change mitigation.

Utilization in Carbon Markets and Private Sector Involvement

Biochar is becoming more popular in the voluntary carbon market outside of academia and policy organizations. Due to their demonstrable sequestration and durability, carbon credits associated with soil application and biochar production are becoming more and more traded, attracting purchasers seeking long-term offsets. In 2023, biochar-based carbon removal credits constituted a major share of delivered CDR credits in voluntary markets. (Woolf et al., 2010)

Prominent business endeavors also indicate growing market awareness. For instance, the multinational internet company Google agreed to buy 100,000 tons of biochar carbon reduction credits produced by agricultural waste efforts in India in 2025. This marks one of the largest biochar-based carbon credit deals to date and reflects corporate willingness to support scalable climate solutions that also benefit rural economies. Such partnerships illustrate how biochar bridges environmental goals with commercial opportunities, particularly where rural farmers receive additional income through carbon credit participation

Adoption on a Regional and National Level

The widespread acceptance of biochar is not only theoretical; it is demonstrated by grassroots initiatives and regional policies. Biochar projects are being started by governments and organizations all around the world to improve soil health, manage trash, and create jobs. For example, a number of state governments and agricultural organizations in India have started initiatives to promote biochar that:

- Encourage infrastructure for the gathering and processing of biomass.
- Include local communities in value chains for sustainable biomass.
- Generate carbon credits to finance ongoing activities.

Biochar is included in national research roadmaps and pilot implementation plans in various areas, including Europe, Australia, the US, and China. While other regions prioritize translation into useful soil management and climate action, China and the United States dominate the world in research output. (Times of India, 2024).

Obstacles and Prospects

Despite significant progress, a number of issues need to be resolved for wider worldwide adoption:

- To guarantee constant performance, biochar production techniques and quality measures should be standardized.
- Economic viability in smallholder situations, where the lack of financial incentives or supportive regulations may make initial investments difficult.
- Long-term monitoring to measure agronomic advantages and carbon persistence under various soil and climate conditions.
- Strengthening capacity to spread best practices, especially in underdeveloped nations with inadequate infrastructure. (Sohi et al., 2009)

Scaling the impact of biochar globally will require strengthening partnerships between government agencies, academic institutions, businesses, and rural communities.

Conclusion

Global recognition of biochar has grown steadily as its multifunctional benefits for climate change mitigation, sustainable agriculture, and environmental management become better understood. Biochar was once thought of as a specialized soil additive, but academics, governments, and international organizations increasingly recognize its capacity to boost soil fertility, water retention, and long-term carbon sequestration. Its importance in lowering greenhouse gas emissions, repairing degraded lands, and bolstering resilient food systems has been shown by scientific research and pilot projects conducted on several continents. As a result, it has been included in international conversations about climate-smart and regenerative agriculture.

Global policy frameworks, carbon markets, and environmental efforts are rapidly incorporating biochar, indicating its shift from experimental technology to an acknowledged climate answer. To guarantee the safe and efficient production and use of biochar, nations are investing in standards, certification programs, and research. This growing global recognition highlights biochar's potential to bridge environmental protection with economic opportunity, particularly for rural and agricultural communities, and positions it as a key component in achieving long-term sustainability and climate goals worldwide

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Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 06

PERSON AND THE PERSONALITY TRAITS

Abstract

Personality traits represent stable, enduring patterns of behavior, emotion, and cognition that distinguish individuals, derived from the Latin *persona* (actor's mask). This article examines the Five-Factor Model—Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism—detailing high/low manifestations, daily examples, and their influence across social interactions, decision-making, and stress management. Understanding these traits fosters self-awareness, personal growth, and improved interpersonal relationships by highlighting individual strengths and adaptive strategies.

Key words: Personality**,** Openness**,** Conscientiousness, Extraversion, Agreeableness, and Neuroticism, the influence of heredity and environment

Introduction

Every individual is unique in how they feel, think and respond to stimuli, creating consistent patterns of behaviour and emotion that define personality. Personality traits serve as key indicators of this uniqueness, revealing deeper insights beyond outward actions. From social interactions to handling stress and making decisions, these traits profoundly influence daily activities. The term "personality" derives from the Latin word *persona*, meaning "mask"—a reference to the theatrical masks worn by actors in ancient times. According to the American Psychological Association (APA, 2018), a personality trait is a relatively stable, consistent, and enduring internal characteristic inferred from patterns of behaviors, attitudes, feelings, and habits. Personality is commonly described through the Five-Factor Model (also known as the Big Five), which identifies key differences in thinking, feeling, and behaving: openness, conscientiousness, extraversion, agreeableness, and neuroticism.

Types of Personality traits

Openness: Individuals high in openness are creative, curious, and eager to learn. They embrace new ideas, changes, imagination, and complex emotions, often questioning traditions in favor of innovation. In contrast, those low in openness prefer routine, tradition, and practical problem-solving.

For example, high-openness individuals enjoy traveling to new places and trying unfamiliar foods, while others stick to daily routines.

Conscientiousness: it refers to the organized, responsible, careful type of person. People with high conscientiousness plan carefully before and work hard to achieve success. They are more disciplined, punctual and goal-oriented in nature. Conscientiousness is reflected in behaviours like being orderly, cautious, neat, detail-oriented and thinking carefully before taking action. Individuals with low conscientiousness show more adaptability, spontaneity, lack of organization and consistency. They can easily adapt to any unpredictable, dynamic situation rather than doing any long-term planning.

In daily life while completing a task some people will plan, organize and schedule it much before, others will work spontaneously and can adapt to any kind of situation.

Extraversion: This personality trait shows the tendency towards a sociable nature. It describes how confident, talkative and externally oriented a person is, which also includes whether social interaction increases or reduces their energy. Extraversion people prefer to be in large groups, enjoy being the center of attraction and have a greater willingness to engage in potentially rewarding activities. On the contrary, introversion is characterized by quietness, solitude and being less sociable. Introvert individuals prefer to have meaningful conversations with few people, reflecting a lower need for social stimulation.

People who are high in extraversion like to enjoy social interaction, like parties, group discussion etc., but introverted person more prefer to stay quiet, read alone, and do their activities quietly.

Agreeableness: characteristics such as sympathetic, kind, cooperative, honest, straightforward type come under this. Agreeableness means how much a person cares about the social relationship, harmony and shows kindness towards others. People who score low on agreeableness are more direct and competitive in nature. They can easily detach emotionally, which allows them to make tough decisions and negotiate efficiently. In daily life, we can see that some friends will listen patiently, offer emotional support, while others argue over small inconveniences and behave rudely.

Neuroticism: This trait is more related to the emotional stability of a person. It explains the individual differences in the tendency to deal with negative emotions and vulnerability to stress. Neurotic people are more likely to be frustrated, irritated by small inconveniences and have poor coping strategies for managing unwanted situations. Emotionally stable individuals are usually calm, balanced types and can handle stressful situations effectively. Low neurotic people can recover quickly from setbacks, but extremely low levels may reduce sensitivity to threats or others' emotional states. Example: A student becomes very anxious before exams and worries more about the results.

Personality traits provide a framework for understanding the pattern of behaviour and emotions that varies from individual to individual. Understanding the pattern will help the individual support personal growth and better interpersonal relationships. It will help the person to understand their strength and weaknesses and how they can use them effectively according to the situation.

Influence of Heredity and Environment

Heredity provides the genetic blueprint (temperament, intelligence potential) and environment (family, culture, experiences) shapes its expression, with both factors constantly interacting to form personality; genetics account for a significant portion (around 40-60%) of trait variation, but life events, learning, and social surroundings mold this potential, with negative experiences often driving significant personality changes and growth.

Genetic Foundation provides the basic raw material for personality, influencing temperament, physique, and innate predispositions. Heritability establishes potential, meaning a person with inherited lower intelligence, for example, can't become a leader regardless of environment.

Early experiences, family dynamics, and cultural values profoundly shape personality development. Negative events (job loss, trauma) often trigger significant personality adaptation and change, while positive events may be less impactful on stability. School, peers, and social groups teach behaviors, values, and how to adjust, allowing for modification of personality patterns.

Neither heredity nor environment acts alone, but they work together in a continuous, dynamic interaction from conception throughout life. Genes' effects depend on the environment, and the environment's impact depends on the genetic framework it interacts with. Individuals actively select and shape their environments, further influencing personality development, creating a feedback loop.

Conclusion

The Big Five traits framework reveals human uniqueness: Openness drives creativity and novelty-seeking; Conscientiousness promotes organization and goal pursuit; Extraversion fuels sociability; Agreeableness nurtures harmony; Neuroticism reflects emotional stability. High/low expressions shape responses to routine, change, and relationships, offering a lens for leveraging personal patterns effectively in diverse situations.

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JUST AGRICULTURE
THE FUTURE OF AGRI INNOVATION

Just Agriculture Multidisciplinary *e- newsletter*

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 07

Payment for Ecosystem Services (PES) in India: Concepts, Status, Challenges and Future Prospects

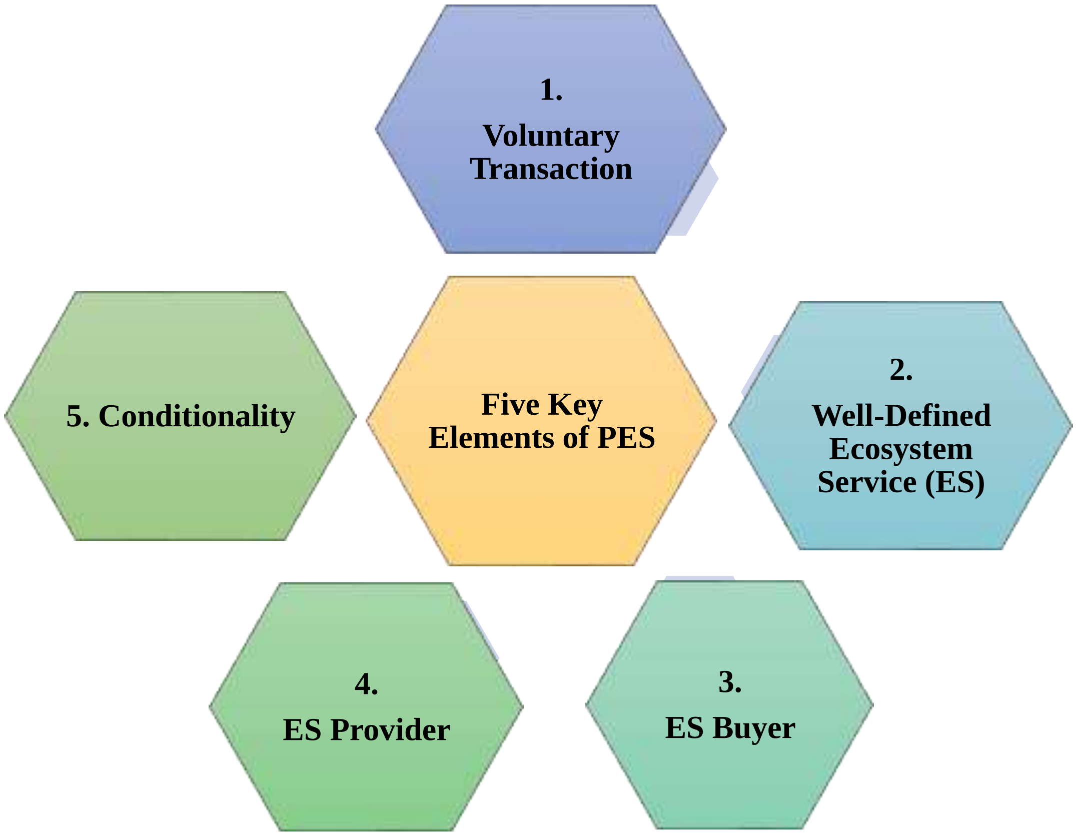
Abstract

Payment for Ecosystem Services (PES) is an emerging policy instrument that aim to conserve natural resources of a country by providing economic incentives to landholders and rural communities who manage ecosystems in ways which sustain or enhance ecosystem services. In India, a vast ecological diversity and dependence of livelihoods on natural resources, offers significant potential for Nature-Based Solution (NBS) approaches through Payment for Ecosystem Services. Although PES in India is still at a blossoming stage, several initiatives related to watershed management, forest management and conservation, biodiversity protection, climate change and carbon sequestration demonstrate its relevance. This article elaborates the conceptual framework of PES, scrutinizes ecosystem services in the Indian context, appraisals existing PES-like mechanisms, highlights challenges and institutional constraints, and discusses future prospects for scaling up of PES as a sustainable development and conservation strategy for greener India and younger generations.

Keywords: Payment for Ecosystem Services (PES), Nature-Based Solution (NBS), forest conservation, sustainable development, greener India

1. Introduction

India is one of the world's most ecologically diverse countries which hosting nearly 8% of global biodiversity and supporting over 17% of the world's population. Forests, grasslands, wetlands, national parks and wildlife sanctuaries, wastelands, agricultural landscapes, and coastal areas provide a wide range of ecosystem services such as air purification, water regulation, carbon sequestration, soil conservation, pollination control, economic, social and cultural benefits. However, increasing population pressure, land-use change, unsuitable development, deforestation, urbanization, climate change, and overexploitation of natural resources have harshly degraded these ecosystems. Traditional conservation approaches of natural resources in India have largely depend on regulatory mechanisms such as protected areas, orchard management, forest and wildlife policies, and community incentives which is governed by the state forestry department.



These approaches have gained certain successes; however, they often overlook the economic realisms of local communities who depend on forest ecosystem resources for their livelihoods. In this context, Payment for Ecosystem Services (PES) has emersed for kind attention as a market-based or economic incentive-driven approach that aligns with conservation objectives of ecosystem as well as livelihood security of the local communities. PES recognizes ecosystem services as valuable economic goods and services seeks to internalize environmental externalities by compensating those who conserve or enhance these ecosystem services (Muradian *et al.*, 2010). In India, PES has significance not only for forest and biodiversity conservation but also for watershed management, agroforestry, climate change mitigation, and sustainable rural development. Hence, there is an urgent need to regularise Payment for Ecosystem Services (PES) mechanisms in India for direct economic benefits to the local communities who involved in conservation of ecosystem services and their livelihoods.

2. Concept and Framework of Payment for Ecosystem Services

The concept of PES was popularized by Wunder (2005) who defined as "a PES is a voluntary transaction where a well-defined ecosystem service (or a land-use likely to secure that service) is being 'bought' by a (minimum one) ecosystem service (ES) buyer from a (minimum one) ecosystem service provider, if and only if the ES provider secures ES provision (conditionality)".

2.1 Key Elements of PES

A PES scheme typically includes the following five key Components of Wunder's Definition (2005) as presented in Fig. 1:

1. **Voluntary Transaction**: A mutual agreement between parties.

2. **Well-Defined Service**: A clear, identifiable ecosystem service (e.g., clean water, carbon sequestration).
3. **Buyer**: A party (individual, community, government) seeking the ecosystem service.
4. **Provider**: A party (often a landowner) supplying the ecosystem service.
5. **Conditionality**: Payment is contingent on actual ecosystem service provision, making it a core element.

2.2 Types of Ecosystem Services

According to the Millennium Ecosystem Assessment (2005), different ecosystem services are categorized into followings:

- **Provisioning services** (food, timber, fuelwood)
- **Regulating services** (climate regulation, water purification, flood control)
- **Supporting services** (soil formation, nutrient cycling) and
- **Cultural services** (recreation, spiritual values).

PES schemes mainly focus on regulating and supporting services which are often undervalued in conventional markets.

3. Ecosystem Services and Their Importance in India

India's economy and rural livelihoods are deeply intertwined with ecosystem services as a long historically sound from India civilization. Forests cover about 25 % of the country's geographical area and play a crucial role in water security, carbon storage, biodiversity conservation, and livelihood support of forest dependent communities. There are several benefits of ecosystem services which has a conceptual framework for ecosystem assessment (Maes *et al.*, 2016) as presented in Fig. 2.

3.1 Forest Ecosystem Services

Indian forests provide:

- Carbon sequestration and climate regulation,
- Watershed protection and groundwater recharge,
- Non-timber forest products (NTFPs) supporting millions of households, and
- Biodiversity habitat and cultural services.

The economic value of these services is rarely reflected in national accounting systems, leading to underinvestment in forest conservation.

3.2 Watershed and Water-Related Services

Watersheds in the Western Ghats, Himalayas, and Central India supply water to major rivers and urban cities. Degradation of catchments due to deforestation, urbanization, industrializations and unsustainable agriculture has increased sedimentation, floods and water scarcity. PES-based watershed protection can link upstream land users with downstream beneficiaries.

3.3 Agroecosystem Services

Agroforestry systems, organic farming and conservation agriculture provide ecosystem services such as soil fertility enhancement, carbon storage, pollination and microclimate regulation. PES can incentivize farmers to adopt sustainable land-use practices.

4. Status of PES in India

Unlike Latin American countries such as Costa Rica and Mexico, India does not yet have a formal, nationwide PES framework. However, several PES-like initiatives exist under different schemes only (Kumar and Thiaw, 2013).

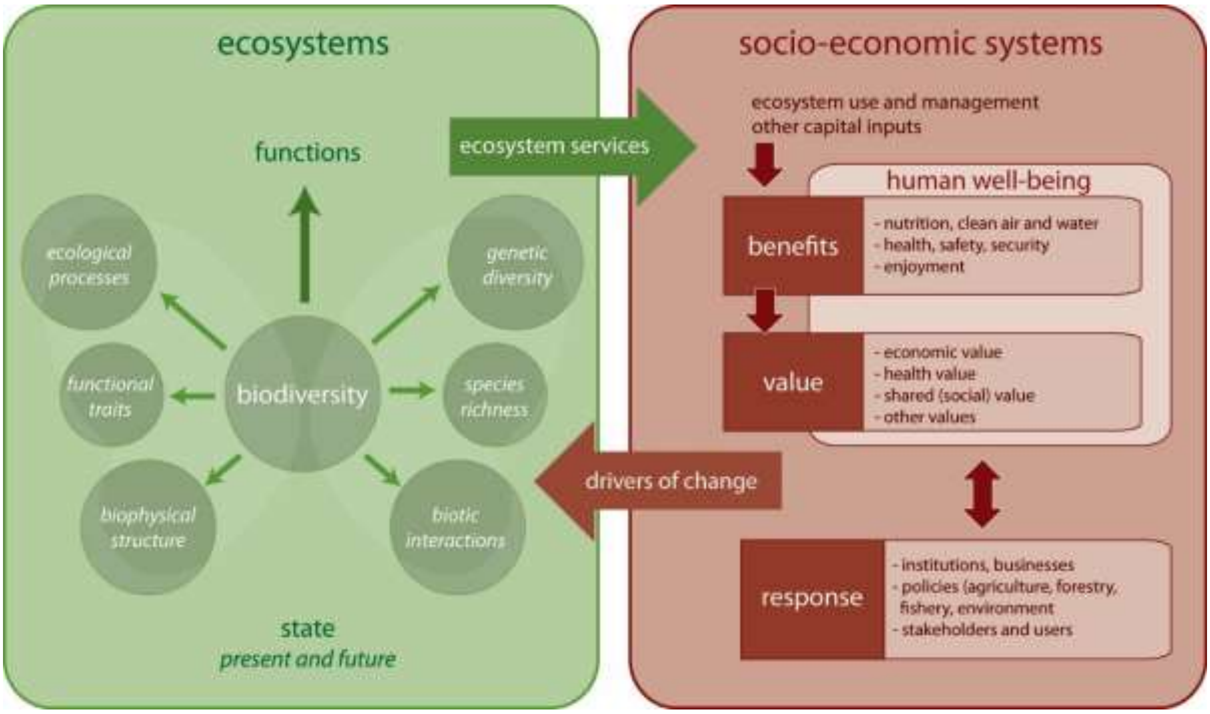


Fig. 2: Conceptual framework for ecosystem assessment (Source: Maes *et al.*, 2016)

4.1 Watershed-Based PES Initiatives

One of the most prominent examples is the Himachal Pradesh Hydropower PES initiative, where hydropower companies compensate upstream communities for catchment area treatment to reduce sedimentation and enhance water flows. Similarly, in parts of Maharashtra and Karnataka, urban water utilities have supported watershed conservation programs to secure drinking water supplies.

4.2 Forest and Biodiversity Conservation

India's Compensatory Afforestation Fund Management and Planning Authority (CAMPA) can be considered a quasi-PES mechanism, where funds collected from forest diversion are used for afforestation and forest conservation. However, CAMPA lacks direct conditional payments to local communities which is a drawback. The Green India Mission and REDD+ readiness activities (GOI, 2018) also align with PES principles by linking forest conservation with climate benefits. However, there is no direct beneficiaries of local communities.

4.3 Carbon Sequestration and Climate Finance

Agroforestry and forest-based carbon projects under voluntary carbon markets provide PES-like payments to farmers and communities for carbon sequestration. India has significant potential in this area due to large-scale agroforestry adoption.

4.4 Biodiversity Offsets and Ecotourism

In certain protected landscapes, ecotourism revenue-sharing and biodiversity offset mechanisms indirectly reward communities for conservation outcomes, although these are not strictly PES schemes.

5. Challenges in Implementing PES in India

Despite its potential, PES implementation in India faces several challenges as following way:

5.1 Institutional and Legal Constraints

- Lack of a clear national PES policy or legal framework,
- Unclear land tenure and forest rights in many regions,
- Fragmented governance across forestry, agriculture and water sectors.

5.2 Valuation and Measurement Issues

- Difficulty in quantifying ecosystem services,
- High transaction and monitoring costs,
- Limited scientific data for outcome-based payments.

5.3 Equity and Social Concerns

- Risk of elite capture and exclusion of marginal communities,
- Need to ensure Free, Prior, and Informed Consent (FPIC),
- Balancing conservation goals with livelihood needs.

5.4 Financial Sustainability

- Limited willingness to pay among beneficiaries,
- Dependence on public funds rather than true market-based mechanisms,
- Uncertain long-term funding.

6. Opportunities and Future Prospects

India's policy landscape presents several opportunities for scaling PES as following way:

6.1 Integration with National Missions

PES can be integrated with:

- National Agroforestry Policy,
- Jal Jeevan Mission,
- National Action Plan on Climate Change (NAPCC), and
- Green Credit Programme.

6.2 Community-Based PES Models

Strengthening community forest management institutions such as Joint Forest Management Committees and Forest Rights Act (FRA) institutions can enhance equitable PES implementation in India.

6.3 Urban–Rural Linkages

Rapid urbanization creates opportunities for urban water users, industries, and municipalities to pay for ecosystem services provided by rural and forested landscapes.

6.4 Role of Research and Capacity Building

Universities, research institutions, and extension agencies can support PES through ecosystem valuation studies, monitoring protocols, and policy design.

7. Conclusion

Payment for Ecosystem Services offers a promising pathway for aligning forest conservation, climate action and rural livelihoods in India. While PES in India is still evolving, existing initiatives demonstrate its feasibility and relevance across forests, watersheds, agroecosystems and climate mitigation efforts. Addressing institutional gaps, ensuring social equity, awareness and building robust valuation and monitoring systems are critical for the success of PES. With appropriate policy support and stakeholder participation, PES can become a transformative tool for sustainable natural resource management in India and social upliftment of local communities.

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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 08

HYDROPONICS FOR SUSTAINABLE VEGETABLE PRODUCTION IN INDIA WITH SPECIAL FOCUS ON LETTUCE

Introduction

Hydroponics represents a modern plant production technique where crops are cultivated without soil and nutrition is supplied directly through carefully prepared nutrient solutions. Growing pressure on land resources, unpredictable climate patterns, and increasing demand for high-quality vegetables have led to the rapid emergence of hydroponics and other protected cultivation systems in India. Vegetables like lettuce show particularly strong responses to protected cultivation due to their delicate physiology and high requirement for controlled conditions. Lettuce has become an important salad crop and its consumption in India is increasing due to changing food habits and greater awareness about health and nutrition. Protected cultivation has been promoted as a method that helps growers regulate the microenvironment around crops to improve yield, ensure better quality, reduce dependence on seasonal conditions, and provide a steady supply to markets throughout the year. Efficient use of water and nutrients, as well as higher photosynthetic rates, are additional advantages of protected conditions.

Protected systems can include soil-based cultivation within structures or a variety of soilless methods such as solution culture, nutrient film technique, deep flow technique, aggregate systems, and aeroponics. Among these techniques, hydroponics has received major global attention because it allows a uniform supply of nutrients, efficient water management, and a high degree of control over plant growth conditions. The nutrient film technique has been widely used for leafy vegetables such as lettuce because it maintains a continuous flow of nutrient solution and provides direct contact between the roots and essential nutrients. Several studies have demonstrated that hydroponics can enhance lettuce growth, improve leaf quality, and support higher productivity compared to conventional open-field cultivation.

In India, where cultivation conditions vary widely across agroclimatic zones, hydroponics offers an opportunity to produce high-value crops with greater uniformity and stability. It allows production in areas with unsuitable soil, limited water, or fluctuating temperatures. With the demand for exotic vegetables growing at approximately fifteen to twenty percent per year, hydroponics is emerging as a significant contributor to future vegetable production strategies. The following sections explore the scientific basis, comparative performance, and nutritional aspects of lettuce grown under hydroponic systems, using information compiled from the provided research materials.

Hydroponic Cultivation and Protected Growing Systems

Hydroponics is a highly controlled growing method in which plants are cultivated in the absence of soil, relying instead on nutrient solutions that supply the essential ions required for growth. In conventional soil-based systems, the soil regulates nutrient release, aeration, and water availability. However, soil is heterogeneous and can impose limitations on nutrient accessibility, pH stability and root development. In contrast, hydroponic systems avoid these limitations by maintaining nutrients in ionic form in the solution and ensuring consistent contact between the roots and the nutrient medium. Early scientific definitions describe hydroponics as plant production in soilless media or directly in nutrient solution where all essential elements are provided in optimum proportions to support plant growth and development

Different protected growing systems include both soil-based and soilless methods. Soil-based protected cultivation benefits from reduced environmental stress but still retains the inherent variability of soil structure and nutrient dynamics. Soilless systems, including hydroponics, allow more precise control over the root zone environment. These systems may involve substrates such as cocopeat, perlite, or rockwool, or may be fully liquid-based. Cocopeat has emerged as an important substrate because it retains moisture, maintains good aeration, and has high rewetting capacity. Studies show that cocopeat supports higher biomass production and enhanced nutrient uptake in various crops compared to other substrates such as rockwool or peat. Increased uptake of potassium, calcium, sulphur and phosphorus has been observed in crops grown in cocopeat, resulting in improved photosynthetic activity and total yield

Nutrient film technique is one of the most efficient hydroponic methods for leafy vegetables because it creates a thin, continuously flowing film of nutrient solution across the root surface. This ensures high oxygen availability, easy nutrient absorption, and minimal water wastage. The system is generally closed and recirculates nutrient solution, reducing input requirements and preventing excessive loss of water and fertilizer. Research reports demonstrate that nutrient film technique produces higher leaf area, greater number of leaves and improved overall biomass in lettuce and other leafy crops when compared with aggregate hydroponics and traditional soil based systems. Recirculating systems require careful monitoring of electrical conductivity and pH but can reduce nutrient and water consumption by twenty to forty percent while enhancing yield and quality

Hydroponics has been described as one of the most intensive crop production systems because it allows direct manipulation of major environmental variables such as nutrient composition, temperature, light, water quantity and aeration. Controlled application of nutrient solutions ensures that plants receive nitrogen, phosphorus, potassium and micronutrients in appropriate proportions. Electrical conductivity is widely used as an indicator of total ionic concentration in nutrient solutions, while pH determines nutrient availability and uptake efficiency. Lettuce grows best when electrical conductivity is maintained between 2.0 and 2.6 deciSiemens per meter, and pH remains between 5.5 and 6.5. Under these conditions, the plants show optimum physiological activity and rapid growth. When maintained correctly, hydroponics can outperform open field cultivation by a factor of ten or more for lettuce, tomatoes and cucumbers. This advantage has been linked to efficient nutrient uptake and reduced environmental fluctuations that commonly affect field crops

Growth Response and Physiological Advantages in Lettuce

Lettuce responds strongly to hydroponic cultivation due to its shallow root system, high sensitivity to temperature and nutrient fluctuations, and requirement for consistent moisture. Multiple studies demonstrate that lettuce grown in nutrient film technique and other hydroponic systems shows improved growth parameters, including plant height, number of leaves, leaf width, leaf area, root mass, and biomass accumulation. Earlier evaluations comparing protected and open field environments show that leafy vegetables in protected structures perform better in terms of vegetative growth, yield and physiological efficiency. Lettuce grown under protected conditions consistently exhibits higher fresh weight, greater leaf area and improved absolute growth rate compared to plants grown in open field conditions

Hydroponic systems enhance physiological functions such as photosynthesis and stomatal conductance because roots receive consistent access to water and nutrients. Studies show that tomatoes and lettuce grown in the nutrient film technique have higher photosynthetic rates than those grown in soil or aggregate systems. Increased stomatal conductance enhances carbon dioxide uptake, further contributing to higher biomass production. In many crops cultivated in protected structures, the regulated microenvironment reduces stress due to temperature fluctuations, thereby improving nutrient assimilation and chlorophyll content. In lettuce grown under hydroponics, chlorophyll content measured through SPAD readings is significantly higher than in soil grown plants. This reflects improved nitrogen uptake, as leaf nitrogen strongly correlates with chlorophyll concentration. Higher chlorophyll content contributes to greater photosynthetic capacity and improved growth efficiency

Hydroponics also influences root development. Roots grown in nutrient film technique or aerated nutrient solutions exhibit healthier growth than those restricted by soil structure. Greater root hair development and reduced mechanical resistance allow more efficient absorption of water and minerals. Studies on cucumber, tomato and lettuce indicate that root fresh weight and dry weight are higher in hydroponic systems. This root advantage directly affects shoot growth, as improved nutrient uptake supports rapid leaf expansion. Protected hydroponic systems also permit better control of light quality and quantity, which can influence photosynthetic activity and leaf pigmentation. For example, specific light sources promote higher photosynthetic rates in lettuce, resulting in faster growth. Temperature regulation is equally important since lettuce performs best at moderate temperatures. Hydroponic systems housed within protected structures help maintain these favourable conditions even in regions with wide climatic variation

In comparative studies, lettuce grown in hydroponics consistently shows greater vegetative vigour than soil based crops. Increased number of leaves, thicker leaf lamina, and higher overall yield have been documented. This is attributed to uninterrupted nutrient availability and the absence of soil-borne constraints. Plants grown in nutrient film technique and cocopeat based systems have been reported to achieve superior morphological and physiological performance compared to those in conventional soil culture. Thus, hydroponics ensures predictable, uniform, and high quality production, especially for leafy vegetables that require continuous nutrient supply and are sensitive to fluctuations in the growing environment.

Figure 1: Lettuce grown using Nutrient Film Technique system

Quality Attributes and Nutritional Improvement in Hydroponic Lettuce

Quality parameters such as nitrate content, vitamin content, chlorophyll level, carotenoid concentration and phenolic composition show strong dependence on the growing system. In lettuce and other leafy vegetables, nitrate accumulation is an important quality indicator. Higher nitrate levels are often associated with rapid growth under low light conditions or excessive nitrogen supply. Studies examining nitrate concentration in different growing systems show that hydroponics, especially nutrient film technique, may result in higher nitrate content due to readily available nutrients. However, nitrate content can be regulated by controlling nitrogen concentration in the nutrient solution and by providing adequate light intensity. For example, floating culture systems show increased nitrate content when nitrogen concentration in the nutrient solution is elevated. Despite this increase, the values remain within the acceptable limits established for leafy vegetables when managed appropriately. Soil grown plants often exhibit lower nitrate levels due to slower nutrient availability from soil reserves, but they may also show reduced uniformity in nutrient accumulation. Rocket and lettuce grown under hydroponics display higher nitrate content but also demonstrate superior mineral composition, including increased potassium, magnesium, and phosphorus content. Aeroponically grown leafy vegetables also exhibit higher mineral uptake compared to substrate-grown plants. Hydroponics significantly influences key nutritional components of lettuce. Studies have reported that lettuce grown in hydroponics contains higher chlorophyll, higher vitamin C, and greater phenolic content compared to soil-grown plants. Chlorophyll content, which reflects nitrogen availability, is consistently higher under hydroponics due to efficient nutrient supply. Vitamin C levels have been observed to be substantially higher in hydroponically grown lettuce, with some cultivars showing more than double the vitamin C content of soil grown equivalents. Phenolic compounds, including anthocyanins in red lettuces, are important antioxidants and contribute to health promoting properties. Red pigmented lettuce types grown hydroponically often show higher phenolic content and intense pigmentation. Anthocyanins such as cyanidin derivatives are responsible for red coloration and their concentration increases under controlled nutrient and light conditions in hydroponic systems. Red lettuces also contain high levels of polyunsaturated fatty acids and carotenoids including beta carotene and lutein. These compounds play important roles in preventing oxidative stress-related diseases. Nutritional composition varies across lettuce types, but hydroponics generally supports higher accumulation of health-beneficial compounds due to optimized nutrition and reduced stress during growth. Carotenoid content is another important indicator of lettuce nutritional quality. Romaine lettuce contains the highest concentration of beta carotene among lettuce types, while crisphead lettuce contains much lower levels. Hydroponic cultivation enhances carotenoid accumulation when compared to soil based cultivation. This may be associated with improved light management and nutrient balance. Baby leaf lettuces, which are increasingly consumed raw, retain their nutritional qualities better when grown under hydroponics because they undergo less environmental stress. Ascorbic acid content is also strongly influenced by the growing system. Studies show that hydroponically grown iceberg and romaine lettuce varieties can contain up to two times more ascorbic acid than soil-grown plants.

Hydroponics also supports higher anthocyanin accumulation in red lettuce, contributing to improved antioxidant capacity. These findings highlight the potential of hydroponic production to improve both the nutritional profile and the consumer acceptability of lettuce and other leafy vegetables in India.

Conclusion

Hydroponics has emerged as a promising approach for sustainable vegetable production and offers clear advantages over traditional soil-based cultivation. Studies on lettuce show that hydroponic systems provide superior control over nutrients, water, and the root environment, resulting in improved growth, higher yield, and enhanced nutritional quality. Increased chlorophyll, vitamin C, and beneficial phytochemicals, along with efficient resource use, make hydroponics an ideal method for producing high-value leafy vegetables throughout the year. With rising demand for safe and nutritious produce in India, hydroponics can play a vital role in strengthening protected cultivation and ensuring consistent supply to consumers.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

ARTICLE ID: 09

VERTICAL TRELLIS SYSTEM: A MODERN APPROACH TO HIGH-QUALITY BOTTLE GOURD PRODUCTION

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Bottle gourd (*Lagenaria siceraria* L.) is an Important vegetable crop Belonging to the family Cucurbitaceae having a chromosome number 2n=22. It is commonly known as calabash gourd, white flowered gourd plant, lauki, Ghiya or doodhi. It is grown extensively with in India and originated in Tropical Africa. It has pan-tropical distribution regional economic importance and is used as a vegetable, musical instrument while its seeds are used for oil and protein. Tender fruits are used as a cooked vegetable and also for preparation of sweets and pickles. Hard shells of mature fruits are used as water jugs, domestic utensils, floats for fishing nets etc. Bottle gourd has relatively high nutritional value. It is a vegetable with a good source of carbohydrates, vitamin A, vitamin C and minerals.

Why the need of Vertical Trellis System?

The traditional way of planting bottle gourd makes it hard for sunlight to reach the lower leaves, which reduces photosynthesis. The thick vine cover also blocks good air movement and increases humidity, creating conditions that favour diseases. Since bottle gourd is a climbing plant, it grows better when given support, which keeps the vines off the ground and helps fruits develop straight. Using a vertical trellis lets the plant grow upward instead of spreading on the soil. This keeps the fruits clean and also allows more plants to be grown in the same area.

What is Vertical Trellis System?

The vertical trellis system refers to the plant system of simple supporting structures used to train vines of bottle gourd upward instead of spreading on the ground. It can be supported by bamboo poles, iron poles, wires or nylon ropes arranged vertically so that vines can easily climb and spread. This system keeps the plant canopy away from the soil, which reduces the problems seen in traditional trailing method, ultimately results in uniform, healthy and disease-free fruits.

Construction of Vertical Trellis System :

The vertical trellis can be constructed using iron pipes or strong bamboo poles of 2–3 m height and about 3 inches in diameter. These poles are arranged vertically at a spacing of approximately 3 m between each pole. After fixing the poles, wires are tied horizontally between them to support the vine canopy and bear the heavy crop load. The plants growing between two poles are initially supported by tying a nylon rope—one end around the stem of the plant and the other end attached to the horizontal wire.

Regular monitoring and tightening of ropes ensure proper support and stability throughout the growing season.

Advantages of Vertical Trellis System :

1. Vertical trellis keeps vines lifted up, which facilitates better light penetration.
2. Better air circulation.
3. Fruits and vines stay off the ground, which reduces disease incidence.
4. Uniform, straight, and healthy fruits can be obtained.
5. Optimum utilization of space.
6. Intercultural operations become easy.
7. Easier pollination because flowers hang freely and facilitate clear visibility to insects.
8. Higher yield and better quality as compared to the traditional method.
9. Higher shelf life of fruits because disease and insect free fruits are obtained.

Challenges & Limitations :

1. Initial cost is high.
2. More number of labourers is needed.
3. Due to heavy crop load during later stages, chances of damage of vines is increased.
4. Harvesting may be difficult when fruits bear on the upper nodes.
5. Spraying of contact pesticides becomes difficult on upper portions of vines.
6. Heavy winds can damage structures easily.
7. Time-to-time maintenance is needed.

Impact of Vertical Trellis System on Yield and Quality:

Sharma *et al.* (2016) conducted a experiment on effect of growing methods on seed yield and quality of bottle gourd. They found a clear advantage of the trailing (trellis) method over the traditional ground trailing method. The number of fruit set per vine increased from 3.48 in the traditional method to 4.08 under trellis. Similarly, the number of mature fruits improved from 2.70 to 3.55. Plants trained on trellis also produced heavier fruits (2.30 kg) and longer fruits (48.49 cm) than those grown traditionally. Even the incidence of fruit rot per vine was slightly reduced under trellis (1.14) compared to the traditional practice (1.21), most yield attributes were significantly better in the trellis system. These results demonstrate that vertical trellising promotes healthier vine growth, better fruit development, and higher marketable yield.

Conclusion : Vertical trailing system is best method for bottle gourd growers. This method is not confined to higher yield but it also provides straight, uniform, insect and disease-free healthy fruits. Farmers can grow more number of plants in less space as compared to traditional trailing method. It is significant approach that every former can adopt easily to obtained higher productivity and profit in bottle gourd farming.

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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 10

FOOD AND NUTRITIONAL SECURITY: STRATEGIES, CHALLENGES AND OPPORTUNITIES

ABSTRACT

Food and nutritional security is a key determinant of human health, livelihood sustainability and socio-economic development. Despite improvements in agricultural production, a significant proportion of the global population continues to suffer from hunger, undernutrition and micronutrient deficiencies. Food security ensures adequate access to food, whereas nutritional security emphasizes dietary quality, diversity and nutrient adequacy. Rapid population growth, climate change, urbanization and income inequalities have intensified pressure on food systems, particularly affecting vulnerable and marginalized communities. This article examines the major strategies, challenges and opportunities related to strengthening food and nutritional security. Important strategies include promotion of nutrition-sensitive agriculture, diversification of cropping systems, climate-resilient farming practices, food fortification, social protection programmes and digital extension services. The role of women empowerment, community participation, institutional coordination and public–private partnerships in improving food availability, access and utilization is also highlighted. Major challenges identified include climate variability, natural resource degradation, post-harvest losses, limited nutrition awareness, poverty and inequitable access to productive resources. These constraints continue to undermine the effectiveness of food and nutrition interventions. At the same time, significant opportunities exist through digital agriculture, innovative food processing technologies, community nutrition initiatives and increased policy focus on nutrition-oriented development. Leveraging these opportunities through integrated and inclusive approaches can enhance food system resilience, improve dietary diversity and ensure sustainable nutritional outcomes. The article concludes that a holistic, multi-sectoral strategy integrating agriculture, health, education and social protection is essential to achieve long-term food and nutritional security and to improve the well-being of vulnerable populations.

Keywords

Food security, Nutritional security, Climate resilience, Nutrition-sensitive agriculture, Sustainable development.

Introduction

Food and nutritional security is a fundamental component of human development and a key priority of global development agendas. While food security focuses on ensuring sufficient availability and access to food, nutritional security emphasizes the quality, diversity and nutrient adequacy of diets required for maintaining good health and productivity. The persistence of hunger, malnutrition and micronutrient deficiencies across the world indicates that food availability alone does not guarantee adequate nutrition. Vulnerable populations, particularly women, children, smallholder farmers and tribal communities, remain disproportionately affected by food and nutrition insecurity.

The global food system is currently facing unprecedented challenges due to rapid population growth, climate change, land degradation, water scarcity, economic inequalities and shifting dietary patterns. Climate variability has adversely affected agricultural productivity, increased the frequency of crop failures and threatened the livelihoods of millions of small farmers. Urbanization and modernization have also altered food consumption patterns, leading to increased reliance on processed foods, which often lack essential nutrients and contribute to diet-related non-communicable diseases.

Despite improvements in agricultural technologies and production levels, malnutrition continues to be a major public health concern in many developing countries. The coexistence of undernutrition, micronutrient deficiencies and rising obesity – known as the triple burden of malnutrition – highlights the urgent need for a comprehensive and integrated approach to food and nutritional security.

Strengthening food and nutritional security requires coordinated efforts across multiple sectors including agriculture, health, education, social protection and environmental management. Nutrition-sensitive agricultural practices, community-based nutrition programmes, women empowerment initiatives and digital innovations have emerged as effective strategies to improve dietary diversity and enhance household resilience. Policy interventions such as food subsidy programmes, school feeding schemes and food fortification initiatives further contribute to improving access to nutritious food.

In this context, understanding the strategies, challenges and opportunities associated with food and nutritional security is essential for designing effective policies and programmes. This article therefore seeks to analyze the key approaches adopted to promote food and nutritional security, identify the major constraints hindering progress and explore emerging opportunities that can be leveraged to achieve sustainable and inclusive food systems.

Strategies for Strengthening Food and Nutritional Security

1. Nutrition-Sensitive Agriculture

Promotes diversification of crops, kitchen gardening, inclusion of fruits, vegetables and pulses to enhance dietary diversity and micronutrient intake.

2. Climate-Resilient Farming Practices

Adoption of drought-tolerant varieties, water conservation techniques and sustainable soil management to stabilize food production.

3. Social Protection and Welfare Programmes

Public Distribution System, mid-day meal schemes and maternity benefit programmes improve food access among vulnerable groups.

4. Food Fortification and Supplementation

Fortification of staple foods with iron, iodine, vitamin A and folic acid helps combat micronutrient deficiencies.

5. Digital Extension and Market Linkages

Mobile-based advisories and digital platforms provide timely information to farmers on production, weather and markets.

Challenges in Food and Nutritional Security

- Climate change and natural resource degradation
- Poverty and income inequality
- Limited nutrition awareness
- Post-harvest losses
- Inadequate access to markets and health services
- Gender disparities and social exclusion

Opportunities for Strengthening Food and Nutritional Security

- Expansion of digital agriculture
- Public–private partnerships
- Community nutrition gardens
- Climate-smart innovations
- Policy focus on nutrition outcomes
- Youth and women entrepreneurship in agri-nutrition sectors

Conclusion

Food and nutritional security is a multidimensional development challenge that requires integrated and sustained interventions. While several constraints continue to hinder progress, emerging strategies and innovations provide promising opportunities to strengthen food systems and improve nutritional outcomes. A holistic, inclusive and multi-sectoral approach that integrates agriculture, health, education, social protection and environmental sustainability is essential to ensure equitable access to nutritious food and build resilient livelihoods for present and future generations.

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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 11

EFFECT OF TILLAGE PRACTICES ON SOIL, CROP PRODUCTIVITY, AND THE ENVIRONMENT

Introduction

Tillage is a fundamental agricultural practice that involves the mechanical manipulation of soil with tools and implements to result in good tilth for better germination and subsequent growth of crops. Traditionally, tillage has been used to prepare seedbeds, control weeds, incorporate residues, and improve soil aeration. However, intensive tillage has been associated with soil degradation, erosion, and loss of soil organic matter. With increasing emphasis on sustainable agriculture, the effects of different tillage practices on soil health, crop productivity, and the environment have gained considerable attention (Brady & Weil, 2017). Understanding and knowledge of these effects is essential for selecting appropriate tillage systems that ensure long-term agricultural sustainability.

Types of Tillage Practices:-

a. Conventional Tillage:

Conventional tillage involves intensive soil disturbance through repeated operations such as ploughing, harrowing, and cultivation. While this system creates a fine seedbed and facilitates early crop establishment, it often leaves the soil bare and vulnerable to erosion (Montgomery, 2007).

b. Reduced and Conservation Tillage:

Reduced tillage minimizes soil disturbance by decreasing the number of tillage operations. Conservation tillage retains at least 30% of crop residues on the soil surface after planting, which helps protect soil from erosion and improves moisture conservation (Hobbs *et al*., 2008).

c. No-Tillage:

No-tillage systems eliminate mechanical soil disturbance except for seed placement. Crop residues remain on the soil surface, enhancing soil structure, increasing organic matter, and promoting biological activity (Derpsch *et al*., 2010).

Effect of Tillage Practices on Soil Properties:-

a. Soil Structure and Aggregation:

Intensive tillage initially improves soil looseness but disrupts soil aggregates over time, leading to compaction and reduced pore continuity. In contrast, conservation and no-tillage systems promote stable soil aggregation due to increased biological activity and reduced disturbance (Six *et al*., 2000).

b. Soil Organic Matter:

Tillage significantly influences soil organic matter dynamics. Conventional tillage accelerates oxidation of organic matter, resulting in long-term declines in soil fertility. Conservation and no-tillage practices help maintain or increase soil organic carbon by reducing decomposition rates and allowing residue accumulation (Lal, 2004).

c. Soil Moisture and Erosion

Residue cover in conservation and no-tillage systems reduces evaporation losses and enhances water infiltration. Conventional tillage leaves soil exposed, increasing runoff and erosion, which leads to loss of nutrients and topsoil (Montgomery, 2007).

Effect on Crop Growth and Yield

Tillage practices influence seed germination, root development, and nutrient availability. Conventional tillage often results in rapid early crop growth, whereas conservation tillage may delay emergence due to cooler soil temperatures. However, long-term studies indicate that conservation and no-tillage systems can sustain or improve crop yields while reducing production costs and enhancing soil health (Rasmussen, 1999; Gupta and Sayre, 2007).

Effect on Soil Biological Activity:

Soil organisms play a vital role in nutrient cycling and soil structure formation. Intensive tillage disrupts soil habitats and reduces microbial diversity. Reduced and no-tillage systems promote higher populations of earthworms and microorganisms, leading to improved nutrient cycling and soil resilience (Karlen *et al*., 2001).

Environmental Effects of Tillage Practices:-

a. Greenhouse Gas Emissions:

Conventional tillage increases carbon dioxide emissions by accelerating organic matter decomposition. No-tillage systems enhance carbon sequestration, contributing to climate change mitigation (Lal, 2004).

b. Energy Use and Water Quality:

Conservation tillage reduces fuel consumption by minimizing field operations. Additionally, reduced erosion and runoff improve water quality by limiting sediment and nutrient transport to water bodies (FAO, 2011).

Challenges of Conservation and No-Tillage:

Despite their advantages, conservation and no-tillage systems face challenges such as increased reliance on herbicides, slower soil warming in cool climates, and the need for specialized equipment. Proper management, crop rotation, and farmer training are essential for successful adoption.

Conclusion:-

Tillage practices have profound effects on soil health, crop productivity, and environmental sustainability. While conventional tillage provides short-term benefits, it often leads to long-term soil degradation. Conservation and no-tillage systems offer sustainable alternatives by improving soil structure, increasing organic matter, reducing erosion, and supporting stable crop yields. Adoption of appropriate tillage practices tailored to local conditions is essential for sustainable agricultural development.

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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

ARTICLE ID: 12

ABNORMAL BEHAVIOURS IN LIVESTOCK: CAUSES AND MANAGEMENT

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Introduction

Livestock such as cattle, sheep, and goats are important sources of income, food, and employment for farmers. Proper care and management are essential for good production and animal health. When animals are kept under poor management conditions, they may develop **abnormal or undesirable behaviours**, known as **vices**. In livestock production, vices refer to abnormal or undesirable behaviours shown by animals. These behaviours may look harmless initially, but over time they can lead to injuries, loss of productivity, health problems, and economic losses. Vices are commonly observed in cattle, sheep, and goats, especially under conditions of confinement, poor nutrition, boredom, overcrowding, and stress. Livestock vices usually develop due to stress, boredom, overcrowding, poor nutrition, mineral deficiency, early weaning, or lack of exercise. These behaviours may seem minor at first, but if they continue, they can cause injuries, reduced milk or meat production, health problems, and economic losses. Some vices also make animals difficult to handle and increase the risk of accidents to handlers.

Common vices seen in livestock include tongue rolling, inter-sucking, pica (eating non-food materials), wool pulling, aggression, and kicking during milking. Most of these problems are management-related and preventable. Early identification of vices and adoption of simple management practices such as balanced feeding, adequate space, proper housing, and gentle handling can effectively control these behaviours. This article highlights the common vices in livestock and practical measures for their management. Understanding the cause behind these behaviours is the first step toward effective control.

Common Vices in Cattle

Cattle vices are often linked to **oral fixation, stress, fear, or nutritional imbalance**.

1. **Tongue Rolling**

This is a repetitive movement where the animal rolls its tongue outside the mouth. It is commonly seen in stall-fed or confined cattle.

Why it happens:

- Boredom and lack of grazing
- Low roughage in the diet
- Genetic tendency in some animals

How to control it: Provide sufficient roughage, allow grazing or exercise, and offer salt or mineral blocks to keep the animal engaged.

1. **Inter-sucking and Cross-sucking**

Calves or even adult animals may suck the udder, ears, or navel of herd mates.

Why it happens:

- Early or abrupt weaning
- Hunger or short feeding duration
- Bucket feeding without nipple stimulation

How to control it: Use nipple feeders, increase feeding time, and avoid very early weaning. Anti-sucking nose plates can be used if the habit persists.

2. **Self-sucking**

Some cows develop the habit of sucking their own udder, leading to milk loss and mastitis.

Why it happens:

- Opportunity combined with hunger
- Habit formation

How to control it: Use anti-suckling nose rings, muzzles, or leather cradles that prevent the animal from bending its neck.

3. **Pica (Eating Non-food Materials)**

Animals may eat soil, wood, plastic, cloth, or even metal.

Why it happens:

- Mineral deficiency, especially salt or phosphorus
- Low fiber intake

How to control it: Ensure balanced mineral supplementation and adequate roughage in the ration.

4. **Kicking During Milking**

Some cows kick violently during milking, posing danger to milkers.

Why it happens:

- Pain, fear, or improper handling
- Udder infections

How to control it: Gentle handling, proper milking technique, and use of anti-kicking straps or belly ropes can help.

Vices in Sheep and Goats

Small ruminants are **highly sensitive to overcrowding and dietary stress**, which makes them prone to behavioural problems.

1. **Wool Pulling and Eating**

Sheep may bite and pull wool from pen-mates.

Main causes:

- Overcrowding
- Protein or roughage deficiency
- External parasites

Control measures: Reduce stocking density, provide continuous access to good-quality hay, and control lice or mites.

2. **Head Butting and Aggression**

Excessive fighting beyond normal dominance behaviour can result in injuries.

Why it happens:

- Competition for feed and space

- Mixing unfamiliar animals

Management: Ensure adequate trough space and group animals of similar size and age. Early disbudding can reduce injury severity.

3. **Lamb or Kid Stealing**

Some ewes or does close to parturition may attempt to claim another animal's newborn.

Why it happens:

- Hormonal changes
- Crowded lambing areas

Prevention: Use individual lambing or kidding pens for 24–48 hours to establish strong mother–offspring bonding.

Special Behavioural Problems of Concern

1. **Buller Steer Syndrome**

In feedlots, one animal may be repeatedly mounted by others, leading to exhaustion, injuries, or even death.

Causes:

- Overcrowding
- Mixing unfamiliar groups
- Hormonal influences

Control: Immediate isolation of the affected animal, reducing group size, and improving pen design.

2. **Abnormal Drinking and Eating Habits**

Urine drinking: Often due to salt deficiency or rumen imbalance.

Dung eating (coprophagy): Seen in calves with mineral deficiency or poor nutrition.

Solution: Provide free-choice salt, correct mineral deficiencies, and ensure balanced feeding.

Repetitive and Stress-related Behaviours (Stereotypies)

Animals under boredom or confinement may show behaviours like bar biting, head rubbing, eye rolling, or excessive self-stimulation.

Best prevention strategy:

- Allow free movement and exercise
- Provide environmental enrichment like chains, rubber objects, or grooming brushes
- Avoid long-term isolation

Golden Rules to Prevent Livestock Vices

- **Check salt availability:** Many pica-related problems disappear once salt is freely available.
- **Add long fiber:** Chewing hay keeps animals occupied and improves rumen health.
- **Reduce overcrowding:** Space reduces stress, aggression, and abnormal behaviours.
- **Handle animals gently:** Calm handling from a young age prevents fear-based vices.
- **Observe early:** Early correction prevents habits from becoming permanent.

Conclusion

Most livestock vices are **management-related, not animal faults**. With proper nutrition, space, enrichment, and gentle handling, these behaviours can be **prevented or corrected**, improving animal welfare as well as farm profitability.

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 13

FERTIGATION: FEEDING CROPS THROUGH IRRIGATION FOR A SUSTAINABLE FUTURE

Why Fertigation Matters Today?

Modern agriculture faces a dual challenge, producing more food for a growing population while using water and fertilizers more efficiently and responsibly. During the Green Revolution, the widespread use of chemical fertilizers and high-yielding crop varieties significantly increased food production. However, over time, it has become clear that simply applying more fertilizer does not guarantee higher yields. In fact, fertilizer use efficiency has been declining, leading to higher production costs and serious environmental problems such as groundwater pollution and soil degradation.

In this context, fertigation has emerged as a smart and sustainable solution. Fertigation refers to the application of fertilizers through the irrigation system, allowing crops to receive both water and nutrients simultaneously, directly in the root zone. By synchronizing irrigation and fertilization, fertigation improves nutrient use efficiency, reduces losses, saves labor, and enhances crop yield and quality. This technique has become especially important with the increasing adoption of drip and other micro-irrigation systems in India and around the world.

What Is Fertigation?

The term "fertigation" is derived from two words *viz.*, fertilizer and irrigation. It is sometimes also referred to as "nutrigation." In simple terms, fertigation is the practice of dissolving fertilizers in irrigation water and delivering this nutrient-rich water to crops through an irrigation network. Unlike conventional fertilizer application methods, such as broadcasting or soil placement, fertigation supplies nutrients directly to the active root zone. In drip irrigation systems, only a small portion of the soil (about 20–30%) is wetted, forming a bulb-shaped wetted area around the roots.

Fig. Modern fertigation technique ensuring efficient water and fertilizer use in crops.

Fertilizers applied through fertigation are concentrated in this wetted bulb, where feeder roots are most active. As a result, crops absorb nutrients more efficiently, and losses due to leaching or runoff are significantly reduced.

A key principle of fertigation is matching nutrient supply with crop demand. Nutrients can be applied frequently and in small doses, ensuring their availability at critical growth stages. This precise control makes fertigation a powerful tool for maximizing productivity while minimizing waste and environmental harm.

A Brief History of Fertigation

Although fertigation is often described as a modern technology, its roots go back thousands of years. One of the earliest examples dates to ancient Athens around 400 BC, where city sewage was used to irrigate tree groves, supplying both water and nutrients. Commercial fertigation began to develop in the mid 20th century. In the 1950s, glasshouse growers in the Netherlands started applying fertilizers through irrigation water. Around the same time, farmers in the United States experimented with injecting ammonia-based fertilizers into surface and furrow irrigation systems.

A major breakthrough occurred in the 1960s in Israel, where the rapid development of micro-irrigation systems went hand in hand with advances in fertigation technology. The introduction of venturi injectors, fertilizer pumps, and later computerized fertigation units greatly improved the accuracy and uniformity of nutrient application. Today, fertigation is widely practiced in horticultural, field, and plantation crops, particularly where drip and sprinkler irrigation systems are used.

Why Fertigation Is Needed?

The need for fertigation becomes especially clear under pressurized irrigation systems such as drip irrigation. In these systems, water is applied only to localized areas near the plant roots. If fertilizers are applied conventionally to the soil surface, much of the nutrient remains outside the wetted zone and becomes unavailable to the crop. As a result, fertilizer efficiency declines sharply. Fertigation overcomes this limitation by ensuring that nutrients move with irrigation water into the root zone. It also helps address several other challenges:

- Uneven nutrient distribution under surface irrigation
- High nutrient losses, especially nitrogen leaching
- Rising costs of fertilizers and labor
- Environmental pollution caused by excess fertilizer use
- By delivering nutrients precisely where and when they are needed, fertigation makes both irrigation and fertilization more effective.

Advantages of Fertigation

Fertigation offers numerous agronomic, economic, and environmental benefits:

* Higher nutrient use efficiency: Nutrients remain available in the moist root zone, leading to better uptake by plants.
* Reduced nutrient losses: Leaching losses can be reduced to around 10%, compared to 40-55% in traditional methods.
* Improved crop yield and quality: Continuous and balanced nutrient supply supports healthy growth and better produce quality.
* Fertilizer savings: Fertilizer requirements can be reduced by 25-50% without sacrificing yield.
* Flexibility in application: Fertilizers can be applied frequently and adjusted according to crop growth stages.
* Labor and energy savings: Fertilizer application through irrigation eliminates the need for manual top dressing.
* Environment-friendly practice: Reduced nutrient losses help prevent soil and water pollution.

Limitations and Challenges

Despite its many advantages, fertigation also has certain limitations:

* High initial investment cost for micro-irrigation and injection equipment
* Risk of uneven nutrient distribution if the irrigation system is poorly designed or maintained
* Possibility of clogging due to chemical reactions or fertilizer precipitation
* Need for corrosion-resistant equipment

* Lack of technical knowledge among farmers regarding fertigation scheduling and fertilizer compatibility
* Addressing these challenges requires proper system design, regular maintenance, and adequate training of users.

Equipment and Fertilizers Used in Fertigation

Successful fertigation depends on two key components: efficient fertilizer injection equipment and appropriately selected fertilizers. The performance of a fertigation system is largely determined by how accurately nutrients are injected into irrigation water and how safely they move through the system without causing clogging or damage.

Injection devices such as bypass tanks, venturi injectors, and fertilizer pumps are used to introduce fertilizer solutions into irrigation lines. Each system has its own advantages and limitations in terms of cost, accuracy, and ease of automation. Bypass tanks are simple and economical devices that operate using a pressure difference in the irrigation line. Water enters the tank, dissolves the fertilizer, and carries it back into the system. These tanks are easy to operate and suitable for orchards and perennial crops, but they offer limited control over nutrient concentration and are not ideal where precise fertigation is required.

Venturi injectors work on the principle of pressure reduction. As water flows through a constricted section of the pipe, a vacuum is created that draws fertilizer solution into the irrigation line. Venturi systems are popular due to their simplicity, low cost, and minimal maintenance requirements. However, they cause some pressure loss and are sensitive to pressure fluctuations, which may affect uniform nutrient application. Fertilizer injection pumps provide the highest level of accuracy and control. These pumps, powered by electricity or hydraulics, inject fertilizer solutions at a predetermined rate, allowing proportional fertigation. They are well suited for high-value crops, greenhouses, and automated systems. Although expensive and more complex, pump injectors ensure uniform nutrient distribution and are compatible with advanced fertigation scheduling.

Fertilizers used in fertigation must be highly soluble, free from impurities, and compatible with irrigation water quality. Poorly soluble fertilizers or those containing insoluble residues can clog filters and emitters, leading to uneven nutrient distribution. Nitrogen fertilizers such as urea, ammonium nitrate, and calcium nitrate are most commonly applied

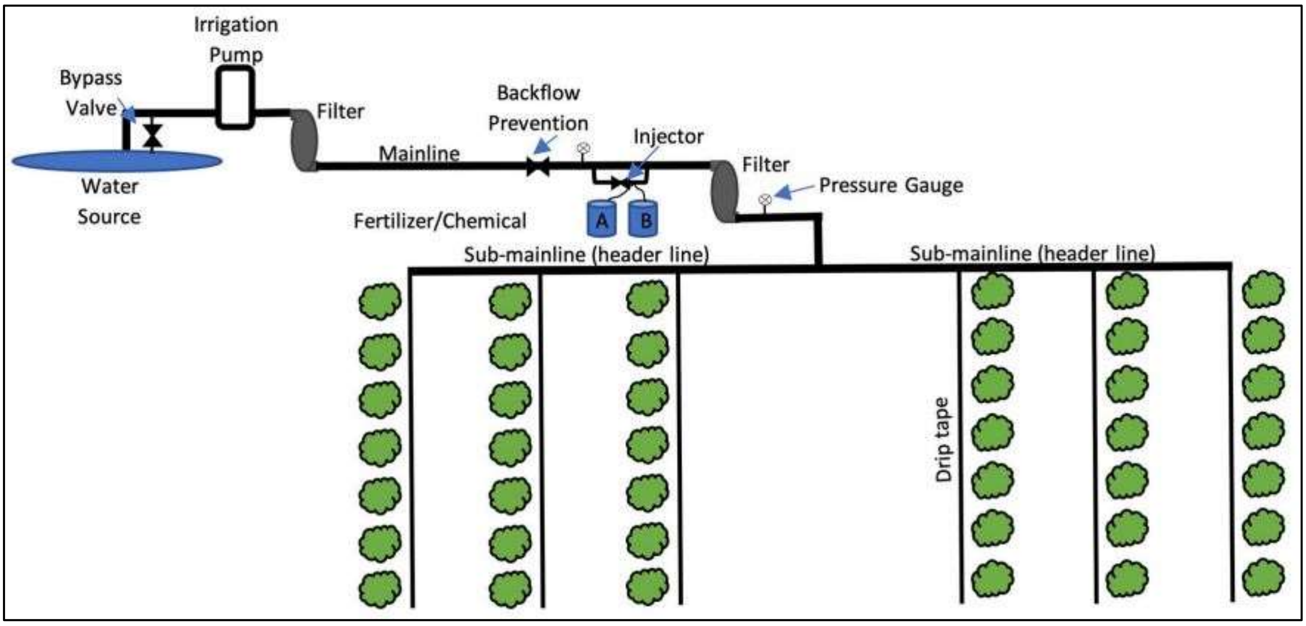

Fig. Fertigation technique in a drip irrigation system

through fertigation due to their high solubility and immediate availability to plants. Potassium fertilizers, particularly potassium nitrate and potassium sulfate, are also widely used. Phosphorus fertilizers and micronutrients can be applied through fertigation, but they require special care because they may precipitate when mixed with calcium- or magnesium-rich irrigation water.

Liquid fertilizers are generally preferred in fertigation systems because they dissolve easily, mix uniformly, and allow precise control of nutrient concentration. Water-soluble solid fertilizers are also used, provided they dissolve completely at field temperatures. Before mixing different fertilizers, compatibility charts should be consulted to avoid chemical reactions that may lead to precipitation and clogging.

Fertigation and Environmental Sustainability

One of the greatest strengths of fertigation is its contribution to sustainable agriculture. By minimizing nutrient losses and improving efficiency, fertigation reduces the risk of nitrate contamination in groundwater and lowers greenhouse gas emissions associated with excessive fertilizer use. It also supports better management of saline soils by allowing controlled leaching and balanced nutrient supply in the root zone.

Conclusion

Fertigation represents a significant step forward in modern crop nutrition management. Combining irrigation and fertilization into a single, efficient operation, it helps farmers achieve higher productivity, better crop quality, and lower input costs. Although the initial investment may be high, the long-term economic and environmental benefits make fertigation an attractive and eco-friendly option for sustainable agriculture. As water scarcity and environmental concerns continue to grow, fertigation, especially when integrated with drip irrigation, will play a crucial role in ensuring food security while conserving natural resources. With proper awareness, training, and policy support, fertigation has the potential to transform agricultural practices in India and beyond.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

ARTICLE ID: 14

ONE PINCH, MANY PODS: IMPORTANCE OF NIPPING IN PULSES

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ABSTRACT

Pulse crops play a crucial role in ensuring nutritional security, improving soil fertility and supporting rural livelihoods. Despite their importance, productivity of pulses often remains below potential due to imbalanced growth and improper crop management practices. Among the low-cost and farmer-friendly techniques available, **nipping** has emerged as an effective agronomic practice to enhance pulse crop yield. Nipping involves the removal of the tender apical bud at an early growth stage, which breaks apical dominance and redirects plant energy towards lateral branching and reproductive growth. By altering hormonal balance, particularly reducing auxin activity and promoting cytokinins, nipping encourages the development of more branches, flowers and pods. This practice improves source–sink balance, enhances light interception, increases nutrient use efficiency and controls excessive vegetative growth. Nipping is especially beneficial in pulse crops such as chickpea, pigeonpea and cowpea, particularly in indeterminate and semi-determinate varieties. When performed at the recommended stage (20–60 days after sowing), depending on the crop), nipping has been reported to increase yields by 10–25 per cent. As a traditional, eco-friendly and cost-free technique, nipping offers a practical solution for improving pulse productivity and sustainability, making it a valuable component of integrated pulse crop management.

Introduction:

Pulse crops occupy a special place in agriculture, nutrition and rural livelihoods. From the humble chickpea curry to protein rich dal served daily in millions of homes, pulses are rightly called the "poor man's meat." They are affordable, nutritious and environment friendly crops that enrich soil fertility through biological nitrogen fixation. Yet, despite their importance, pulses yield often remain low compared to their potential. Among the many reasons for this yield gap, improper crop management practices play a major role. One such simple but highly effective practice is nipping. Nipping is a traditional technique that requires no machinery, no chemicals and almost no cost, just timely human attention.

Understanding Pulse Crops and Their Growth Habit

Pulse crops such as chickpea, pigeonpea, green gram, black gram, lentil, field pea and cowpea have a unique growth pattern. Most pulses exhibit apical dominance, meaning the main stem grows faster and stronger than side branches.

This leads to taller plants, fewer lateral branches, limited flowering points and reduced pod-bearing area. In many cases, pulse plants invest excessive energy in vegetative growth (leaves and stems) rather than reproductive growth (flowers and pods). This imbalance results in poor pod setting and low yields, even when the crop appears lush and healthy.

What is Nipping?

Nipping is the removal of the tender terminal growing point (apical bud) of a pulse plant at an early growth stage. It is usually done by manually pinching the top portion of the plant using fingers. This practice breaks apical dominance and redirects the plant's energy toward lateral growth and reproductive development. In simple words, nipping tells the plant: "Stop growing taller, start producing more branches and pods."

Historical and Traditional Roots of Nipping

Nipping is not a new practice. Long before scientific research validated its benefits, farmers in many regions practiced nipping intuitively. Traditional farmers observed that plants that were grazed lightly or damaged at the top often produced more branches and pods in many crops including cereals. Over time, this observation evolved into a deliberate agronomic practice, especially in crops like pigeonpea and chickpea.

Scientific Basis of Nipping

Breaking Apical Dominance

The apical bud produces a plant hormone called **auxin,** which suppresses the growth of lateral buds. When the apical bud is removed:

- Auxin concentration decreases
- Cytokinin (branch / lateral growth-promoting hormone) become more active
- Dormant lateral buds start growing

This hormonal shift leads to **more branching,** which directly increases the number of sites for flowering and pod formation.

Better Source–Sink Balance

Leaves are the source of plant food, the photosynthates. While, flowers and pods are the sink, edible or economic part of plant biomass. Excessive vegetative growth creates imbalance. Nipping helps maintain a proper **source–sink relationship,** ensuring photosynthates are efficiently diverted toward pod development.

Why Nipping is Important in Pulses

1. Promotes More Branching: Each branch in a pulse plant has the potential to bear flowers and pods. Nipping increases the number of branches, leading to a bushy and well-spread plant canopy which will also intercept more sunlight to become self-sufficient in terms of food reserve required to sustain additional flowers and pods on the branches.

2. Increases Flowering and Pod Formation: More branches mean more flowering nodes. Nipped plants show better flower retention and improved pod setting compared to non-nipped plants.

3. Controls Excessive Vegetative Growth: In crops like pigeonpea, plants often grow too tall, especially under high fertility or high rainfall conditions. Nipping restricts unnecessary tallness and encourages compact plant architecture.

4. Improves Light interception: Bushy plants with well-distributed branches allow better sunlight interception by the canopy. This improves photosynthesis and reduces disease incidence by maintaining desired microclimate.

5. Enhances Nutrient Use Efficiency: Instead of wasting nutrients on unnecessary stem elongation, the plant utilizes available nutrients for reproductive growth reflected in the economic yield of the crop.

6. Increases Yield: Several studies and field demonstrations have reported 10–25 percent yield enhancement due to timely nipping depending on crop, variety and environmental conditions.

Pulse Crops Suitable for Nipping

Nipping is particularly beneficial in:

- Chickpea
- Pigeonpea
- Cowpea

However, it is most effective in **indeterminate and semi-determinate, tall growing varieties** with continued vegetative growth alongside flowering.

Right Time for Nipping

Timing is crucial for successful nipping. If done too early or too late, the benefits may reduce.

Recommended Time (General Guidelines)

- **Chickpea:** 25–30 days after sowing
- **Pigeon pea:** 30–50 days after sowing
- **Cowpea:** 20–30 days after sowing

At this stage, plants are well established with sufficient leaf area for crucial phase of the vegetative growth, the branching. The growth in this phase decides the yield bearing capacity of the plant which influences the number of flowers and branches.

How to Perform Nipping

Method

- Use fingers to gently pinch off the top 2–3 cm of the top most part of the shoot.
- Ensure the plant is healthy and actively growing.

Manual nipping is the traditional practice followed, but now simple, economical tools like nipping machines are available are available which reduces dependency on human labour and quicker as well.

Best Time of Day: Morning or evening hours are ideal to reduce stress on the plant.

Conclusion: In agriculture, not all solutions need to be expensive or complex. Sometimes, the most powerful practices are the simplest ones. Nipping in pulses is a perfect example of this truth. By removing a small portion of the tip of the plant at the right stage, farmers can dramatically improve branching, flowering, pod formation, and ultimately the crop yield. Additionally, it involves less effort, and money to realize a remarkable yield increase. By adopting nipping as a regular practice, farmers can enhance productivity, profitability and sustainability of pulse farming.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 15

Enhancing Productivity through Smart and Sustainable Agriculture: A Roadmap for Viksit Bharat @2047

Introduction

Agriculture has always been the backbone of India's economy and cultural identity, contributing approximately 18.3% to the nation GDP and employing nearly 45.5% of the workforce. As the nation envisions becoming a developed country by 2047, enhancing agricultural productivity through smart and sustainable approaches becomes not just desirable but essential. With India housing 18% of the world's population but possessing only 4% of its fresh water resources, the country must transform its agri-food systems. We must shift from traditional production models to resilient, technology-driven, and environmentally responsible frameworks. Smart and sustainable agriculture represents the convergence of digital innovation, ecological stewardship, and farmer-centric strategies—paving the way for a prosperous, food-secure, and globally competitive Bharat.

Technological Integration: From Input-Intensive to Precision-Intensive

Productivity enhancement requires a paradigm shift from input-intensive growth to knowledge- and precision-intensive growth. The integration of advanced technologies such as Artificial Intelligence (AI), Internet of Things (IoT), drones, and Big Data analytics is reshaping Indian agriculture.

Precision farming tools allow farmers to apply water, nutrients, and pesticides in optimal quantities. For instance, drone technology is now being used for spraying Nano Urea, which reduces chemical usage by up to 25% while improving crop efficiency. Smart sensors and automated irrigation systems enable real-time monitoring of soil moisture and plant health. The Government's Digital Agriculture Mission and the creation of AgriStack—a unified database of farmers—are accelerating these innovations, ensuring that schemes reach the intended beneficiaries transparently.

Sustainability: The Twin Pillar of Growth

Sustainability must operate alongside technological advancement. India's future productivity gains must come from restoring soil health and conserving natural resources. The "Green Revolution" increased yields but often at the cost of soil degradation. Today, the focus has shifted to Regenerative Agriculture. Adopting biofertilizers, zero-budget natural farming, and green manuring helps rejuvenate degraded soils.

Water efficiency is equally critical; under the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), the mantra of "Per Drop More Crop" promotes micro-irrigation (drip and sprinkler systems), which has demonstrated water savings of 30-50% in crops like sugarcane and bananas. Furthermore, the PM-KUSUM scheme encourages the use of solar pumps, reducing the carbon footprint of irrigation while providing farmers with an additional income source through surplus power generation.

Real-World Success Stories and Case Studies

Case Study 1: AI in Telangana (Precision Agriculture)

In a pilot project implemented in Telangana, the state government collaborated with technology giants to use AI for sowing advisories. By analyzing historical weather data, soil moisture, and rainfall patterns, the AI system sent text messages to farmers advising the optimal sowing date. The result was a remarkable 30% increase in yield for farmers who followed the advisory, without any additional capital expenditure.

Case Study 2: Sikkim's Organic Model (Sustainability)

Sikkim stands as a global beacon of sustainability as the world's first 100% organic state. By banning chemical fertilizers and pesticides, Sikkim has not only preserved its biodiversity but also positioned its produce in the premium market. This shift has improved the long-term health of the soil and ensured high-value returns for farmers, proving that sustainability and profitability can coexist.

Case Study 3: DeHaat (Agri-Tech Innovation)

DeHaat, a homegrown agri-tech startup, demonstrates the power of private sector innovation. It offers an AI-enabled "seeds to market" platform connecting over a million farmers. By providing soil testing, customized crop advice, and direct market linkage, DeHaat has helped farmers increase their income by up to 50%, solving the fragmentation issue in the supply chain.

Institutional Support and Post-Harvest Management

Technology alone cannot solve the crisis; institutional reforms are vital. The government's ambitious target to form 10,000 Farmer Producer Organizations (FPOs) is a game-changer. FPOs allow smallholders to pool resources, bargain collectively, and access modern machinery that would be too expensive individually.

Furthermore, post-harvest losses in India are estimated to be around ₹92,000 crore annually (CIPHET data). Smart supply-chain technologies—such as cold storage chains, blockchain-based traceability, and digital marketplaces like e-NAM (National Agriculture Market)—are critical. These systems reduce wastage and ensure farmers get a fair share of the consumer's rupee.

Conclusion: The Path to Viksit Bharat

Moving forward, the roadmap to Viksit Bharat @2047 requires a multi-dimensional strategy. It involves accelerating digital transformation, strengthening human capital by training rural youth in agri-tech, and investing heavily in R&D. Productivity must not be viewed merely as an increase in tonnage, but as the enhancement of efficiency, nutritional quality, environmental integrity, and farmer well-being.

In conclusion, smart and sustainable agriculture is the cornerstone of India's journey towards becoming a developed nation. By embracing intelligent technologies like AI and drones, alongside sustainable wisdom like organic farming and water conservation, India can empower its Annadatas (food providers). This transformation is not just an economic necessity but a moral imperative to safeguard our natural resources for future generations.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 16

DRUDGERY REDUCING TECHNOLOGIES FOR WOMEN IN AGRICULTURE

INTRODUCTION

Women form the backbone of Indian agriculture. From sowing to storage, women contribute tirelessly to farming operations, livestock care, and household chores. Despite their enormous contribution, the majority of their work remains unrecognized and unpaid. Studies indicate that rural women spend **129 minutes in cooking**, **113 minutes fetching water**, and **62 minutes washing clothes** daily (Singh et al., 2019). They often work **16 hours or more**, balancing both farm and domestic roles.

India, having completed 75 years of independence, celebrates *Azaadi Ka Amrit Mahotsav*, highlighting "**Empowered Women – Empowered Nation**". With **54.6% of the national workforce** engaged in agriculture (Census 2011), women hold a particularly crucial role. As per MoSPI (2017), **women's agricultural workforce participation is 77.11%**, significantly higher than many sectors.

However, farm women are disproportionately affected by **drudgery**, defined as physical and mental strain, repetitive discomfort, and health stress. Their involvement in bending, squatting, heavy loads, and repetitive motions causes musculoskeletal disorders, fatigue, back pain, knee injuries, and reduced productivity. Traditional tools often ignore women's body dimensions and ergonomics.

Thus, **reducing drudgery** and **improving safety** through ergonomic tools is essential. Ergonomics focuses on fitting tools and tasks to human capability, creating safer and more efficient work environments.

UNDERSTANDING ERGONOMICS IN AGRICULTURE

Ergonomics aims to achieve a perfect match between workers and their work environment by studying:

- Physical capabilities of the human body
- Limitations of posture, movement, force, and reach
- Nature of tools used
- Workplace environment

The goal is to ensure **safety, comfort, productivity, and injury prevention**. In agriculture, ergonomic interventions significantly reduce strain, improve posture, and enhance efficiency.

KEY ERGONOMIC PRINCIPLES

Principle 1: Work in Neutral Postures

Neutral posture maintains the natural 'S' curve of the spine. Bending in an inverted 'V' posture increases spinal pressure. Tools such as lifters, adjustable handles, and raised platforms reduce harmful posture.

Principle 2: Reduce Excessive Force

Tasks requiring high force, like pulling carts or handling heavy boxes, increase injury risk. Solutions include:

- Proper wheels
- Hand grips
- Power-operated alternatives
- Handholds on boxes significantly reduce hand strain.

Principle 3: Keep Everything Within Easy Reach

The "reach envelope" helps avoid stretching and twisting. Frequently used items must remain within arm's reach. Tilting boxes or bringing materials closer minimizes movement.

Principle 4: Work at Proper Height

Most tasks should be performed at **elbow height**.

Exceptions:

- Heavy work → below elbow
- Precision work → above elbow

Adjustable tables are very effective.

Principle 5: Reduce Excessive Motions

Repetitive actions lifting, twisting, or reaching cause fatigue. Rearranging workstations, using sliding rather than lifting, and minimizing unnecessary movements reduces strain.

Principle 6: Lift Safely

- Keep load close
- Bend knees, not back
- Use leg muscles for lifting

Principle 7: Minimize Fatigue and Static Load

Static positions like squatting, overhead work, or standing for long hours cause fatigue. Frequent posture changes, footrests, and extended handles help.

Principle 8: Provide Adequate Clearance

Ensure enough space for head, knees, and feet. Good visibility and freedom of movement are essential, especially while using bulky tools.

Principle 9: Move, Exercise, and Stretch

Physical activity prevents stiffness. Workers should change posture, stretch, and walk periodically.

Principle 10: Maintain a Comfortable Working Environment

Proper lighting, heat reduction, low vibration, and dust control improve productivity and comfort.

HEALTH HAZARDS COMMONLY FACED BY FARM WOMEN

Women in agriculture face numerous occupational hazards:

Skin Allergies & Poisoning

- Seed treatment
- Pesticide application
- Threshing, winnowing

Injuries: Cuts, Wounds, Swelling

- Weeding
- Harvesting
- Digging
- Land preparation

Sun Stroke & Fatigue

- Sowing
- Irrigation

- Harvesting

Body Ache & Tiredness

- Fetching water, fodder, firewood
- Threshing
- Cleaning barns and sheds

Bites & Stings

- Weeding
- Grazing animals

Drudgery-reducing tools significantly minimize these hazards.

DRUDGERY REDUCING TOOLS FOR WOMEN IN AGRICULTURE

A. Seed Treatment

1. Seed Treatment Drum

- Uniform chemical mixing
- Avoids bending posture
- Capacity: **200 kg/hr**
- Prevents direct contact with chemicals

B. Fertilizer Application

1. Fertilizer Broadcaster (Refined for Women)

- Shoulder-mounted with cushioning
- Uniform fertilizer spread
- Capacity: **1.15 ha/hr**
- Productivity increased **3 times**
- Saves **6% cardiac cost**

C. Rice Transplanting

1. Two-row Rice Transplanter

- For mat-type seedlings
- Avoids bending posture
- Capacity: **61 m²/hr**
- Increases productivity by **79%**

D. Weeding Tools

1. Twin Wheel Hoe

- Push–pull action
- Capacity: **150 m²/hr**
- Reduces bending
- Saves **43% cardiac cost**

2. Cono Weeder

- For wetland paddy
- Operated standing
- Capacity: **120 m²/hr**

E. Harvesting & Fodder Cutting

1. Improved Serrated Sickle

- Lightweight (180 g)
- Requires no frequent sharpening
- Saves **15% cardiac cost**

F. Grain Cleaning

1. Hanging Grain Cleaner

- Increases productivity 4 times
- Saves **63% cardiac cost**
- Capacity: **225 kg/hr**

2. Finger Millet Thresher Cum Pearler

- Powered by 2 HP motor
- Saves **80% time**
- Labour saving: **5.38 times**

G. Groundnut Processing

1. Sitting-type Groundnut Decorticator

- Capacity: **30 kg/hr**
- Saves **79% cardiac cost**
- Very user-friendly for women

2. Groundnut Stripper

- Allows 4 women working simultaneously
- Adjustable stool prevents knee pain
- Output: **350 kg/day** vs 200 kg traditionally

H. Sugarcane Operations

1. Sugarcane Stripper

- Safe and efficient leaf stripping
- Capacity: **46 kg/hr**
- Reduces injury risk

I. Vegetable Transportation

1. Head Load Manager

- Transfers weight from head to shoulder/back

- Capacity: **20–30 kg/trip**
- Reduces perceived exertion

J. Arecanut Dehusking

1. Rotary Arecanut Dehusker

- No injury risk
- Capacity: **5 kg/hr**

K. Cashew Processing

1. Green Cashewnut Sheller

- Shelling efficiency: **98%**
- Output: **120–140 nuts/hr**

L. Milking

1. Revolving Milking Stool and Stand

- Improves posture
- Reduces body discomfort by **32%**
- Mobile and easily fabricated

M. Water Fetching

1. Water Wheel

- Capacity: **45 litres/wheel**
- Reduces pull force and muscular pain

CONCLUSION

Women are indispensable to agriculture, yet face immense drudgery and health risks.

- There is a need for researchers to make agricultural health and safety as a priority
- Need to develop low-cost, convenient technologies
- Need to train farm women about using women friendly agriculture technologies and operating improved tools and equipment.
- There is a need for conducting awareness, intervention and prevention programs about health disorders for farm women.

Empowering women through technology is not only a necessity but a commitment to national progress. As India moves toward modernization of agriculture, **drudgery reduction for farm women** must remain a central focus.

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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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Application of Remote Sensing and AI in Precision Orchard Management: A Paradigm Shift in Modern Horticulture

Abstract

The transition from traditional fruit farming to Precision Orchard Management (POM) represents a critical evolution in agriculture. Faced with challenges such as labor shortages, climate change, and the need for higher resource use efficiency, orchardists are turning to digital solutions. This article explores the synergistic application of Remote Sensing (RS)—including Unmanned Aerial Vehicles (UAVs) and satellite imagery—and Artificial Intelligence (AI) algorithms. It details how these technologies facilitate individual tree management, automated yield estimation, and early disease detection. Through specific case studies and a review of current literature, we demonstrate that RS and AI are no longer futuristic concepts but essential tools for sustainable profitability in fruit science.

1. Introduction

Orchard management has historically been a labor-intensive practice relying heavily on the grower's intuition and manual sampling. However, the spatial variability in orchards—where soil type, moisture, and tree vigor vary significantly within a single hectare—means that uniform management (treating every tree the same) often leads to wasted inputs and suboptimal yields.

Precision Orchard Management (POM) aims to manage this variability by treating individual trees or small zones as unique units. The backbone of POM is data. Today, two technologies are driving this data revolution:

Remote Sensing (RS): The acquisition of information about the orchard without physical contact, using sensors mounted on satellites, aircraft, or drones (UAVs).

Artificial Intelligence (AI): Specifically Machine Learning (ML) and Deep Learning (DL), which process the vast amounts of visual data collected by RS to make actionable decisions.

The convergence of these technologies allows for "Smart Horticulture," where decisions regarding irrigation, fertilization, and harvesting are data-driven, precise, and automated.

2. Technological Framework

2.1 Remote Sensing Platforms and Sensors

Remote sensing in orchards operates on three levels:

- **Satellite Imagery:** Useful for macro-analysis of large estates. Platforms like Sentinel-2 provide normalized difference vegetation index (NDVI) data to monitor general canopy vigor.
- **UAVs (Drones):** The workhorse of moder POM. Drones fly at low altitudes, providin centimeter-level resolution. They utilize:
- RGB Cameras: For visual inspection an counting.
- Multispectral Sensors: To capture Near-Infrared (NIR) light, which reveals plant health before the human eye can see stress.
- LiDAR (Light Detection and Ranging): Laser scanning that creates 3D models of tree structure, essential for biomass estimation.
- **Ground-Based Proximal Sensing:** Tracto equipped with cameras and LiDAR that scan tree row-by-row for real-time spraying adjustments.

2.2 The Role of Artificial Intelligence

Raw images are useless without interpretation. A acts as the "brain" of the operation.

- **Computer Vision:** Convolutional Neural Networks (CNNs) are trained to "see" fruit. Algorithms like YOLO (You Only Look Once) can detect and box individual apples or oranges in a video stream in milliseconds.
- **Predictive Modeling:** Machine learning mode analyze historical weather data and curre spectral data to predict harvest dates and potenti pest outbreaks.

3. Key Applications in Fruit Science

3.1 Automated Tree Inventory and Canopy Management

In large commercial orchards, maintaining an accurate count of trees and their health status is difficult. AI models applied to drone imagery can automatically count trees, detect gaps (missing trees), and measure canopy volume.

- Application: LiDAR data helps calculate the Leaf Area Index (LAI), allowing growers to adjust pruning strategies and variable-rate sprayer nozzles to target only the foliage, saving up to 30% on pesticides.

3.2 Yield Estimation and Fruit Counting

Accurate yield estimation is the "Holy Grail" of orchard management. Traditional manual counting has an error margin of 20-30%.

- Mechanism: Computer vision systems scan trees during the growing season. The AI identifies visible fruit and uses geometric models to estimate occluded (hidden) fruit.
- Benefit: This allows better logistics planning (ordering boxes, booking trucks) and marketing strategies before the harvest begins.

3.3 Water Stress and Irrigation Scheduling

Thermal remote sensing is critical here. Trees close their stomata under water stress, raising canopy temperature.

- Mechanism: Thermal cameras on drones measure Crop Water Stress Index (CWSI). AI integrates this with soil moisture data to automate drip irrigation systems, delivering water only to thirsty zones (Variable Rate Irrigation).

4. Detailed Case Studies

To understand the practical viability of thes technologies, we examine three specifi implementations.

Case Study I: Apple Yield Estimation usin Deep Learning

- **Context:** A commercial Apple orchard i Washington State, USA, faced logistical issue due to inaccurate yield forecasts.
- **Technology Used:** A tractor-mounted machine vision system equipped with stereo-cameras and strobe lights for night-time imaging (to reduce shadow interference).
- **Methodology:** The system captured images (the canopy. A Deep Learning model (Faster F CNN) was trained on 5,000 annotated images (apples. The algorithm detected apples an measured their diameter in real-time.
- **Outcome:** The AI system achieved a detectio accuracy of **92%**. By mapping the fruit count t GPS coordinates, the grower created a "Yiel Map." This allowed the grower to perforı "Precision Thinning"—removing excess fru.. from overloaded trees early in the season t ensure uniform fruit size and prevent bienni bearing.

Case Study II: Early Detection of HLB (Citru Greening)

- **Context:** Huanglongbing (HLB) is a devastating bacterial disease in citrus. Once visible symptoms (yellowing) appear, the tree is already declining.
- **Technology Used:** UAV-based Hyperspectral Imaging.
- **Methodology:** Researchers used hyperspectra sensors that capture hundreds of narrow ligl bands. Healthy trees and infected trees reflec light differently in the "Red-Edge" spectrum (680–750 nm). Machine Learning algorithms (Support Vector Machines - SVM) were trained to distinguish these specific spectral signatures.
- **Outcome:** The system successfully identified infected trees **4 to 6 weeks before visual symptoms appeared**. This allowed for the rapid removal of infected trees (roguing) to save the rest of the orchard, a capability impossible with human scouting alone.

Case Study III: Automated Mango Harvesting Robotics

- **Context:** Labor shortages during the mango harvest peak in Australia.
- **Technology Used:** LiDAR for depth sensing and RGB cameras for color detection, integrated into a robotic arm.
- **Methodology:** The AI system had to distinguish between ripe (colored) and unripe fruit and navigate branches without damaging the tree. The "Soft-Grip" technology utilized pressure sensors to hold the fruit.
- **Outcome:** While slower than human pickers initially, the robot could work 24 hours a day. It achieved a harvest success rate of 76% with zero fruit damage. The study highlighted that orchard architecture (trellis systems) must change to accommodate robots (e.g., high-density planting).

5. Challenges and Barriers to Adoption

Despite the potential, several hurdles prevent widespread adoption, particularly in developing economies:

1. **High Initial Capital:** Hyperspectral cameras and heavy-lift drones are expensive. Smallholder farmers cannot afford them individually.

2. **Data Processing Bottlenecks:** A 20-minute multispectral drone flight can generate 50GB of data. Processing this requires high-performance computing and stable internet, often lacking in rural areas.
3. **Complexity of Biological Systems:** Unlike factory widgets, fruit trees are complex 3D structures. Occlusion (leaves hiding fruit) remains a major challenge for AI counting, often requiring "Correction Factors" which can introduce errors.
4. **Standardization:** There is a lack of standardized software platforms. Farmers often struggle with interoperability between their drone data and their tractor computers.

6. Future Prospects: Digital Twins and Metaverse

The future of orchard management lies in **"Digital Twins."** This involves creating a virtual replica of the physical orchard. Sensors will feed real-time data to the digital twin. The farmer can simulate scenarios on the computer (e.g., "What happens if I reduce water by 10%") before applying them in reality. Furthermore, the integration of **Edge Computing** will allow drones to process data on-board, eliminating the need to upload huge files to the cloud.

7. Conclusion

The application of Remote Sensing and AI in fruit science is not merely an upgrade; it is a necessary transformation. By shifting from "Hectare-level" management to "Tree-level" management, growers can optimize inputs, reduce environmental impact, and secure higher yields.

While challenges regarding cost and technical complexity exist, the rise of "Farming-as-a-Service" (FaaS) models—where startups provide drone services to farmers on a rental basis—will likely democratize access. For young entrepreneurs and researchers in horticulture, the intersection of biology and technology offers the most fertile ground for innovation in the coming decade.

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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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TRADITIONAL QUALITY RICE OF ASSAM: A REPOSITORY OF HERITAGE

Introduction:

Agriculture remains the fundamental pillar of India's rural economy . The sector registered a **c**ompound growth rate of 2.1 % per annum during 2013–14 to 2022–23 and an average annual growth rising to 4.18 % in recent years (Economic Survey 2023–24). Since the Green Revolution of the 1960s, India's food grain production has risen sharply from 82 million tonnes in 1960–61 **to** 357.73 million tonnes in 2024–25**.** Rice plays a pivotal role in Indian agriculture, and in 2024–25**,** India became the world's largest rice producer**,** surpassing China with 150.18 million tonnes of rice production**.** Rice is the staple food for Assam and the Northeast India as in many parts of the world. Being a biodiversity hotspot the region is rich in both floristic and crop diversities, where rice is occupying around 80% of the total cultivated area of this region. Rice covers 2.54 million ha of **gross** cropped area and contributes nearly 96 % of Assam's total food grain production**.**

The NE India is the home of many locally adapted traditional land races of rice. It has been estimated that at least 10,000 indigenous cultivars are prevailing in the North-eastern region of India. The farmers of this region still grow their heirloom cultivars which not only suit to their taste but also provide food security. The indigenous rice cultivars are popular for its unique aroma, good cooking qualities and excellent palatability. This rice germplasms has considerable variation in grain size, shape, awn and glume characteristics. They are mainly used for preparing special dishes in festive occasions and marriage ceremonies. These cultivars with special traits also known as specialty rice paved the way to domestic and international market in recent years. Each state of northeast has their own indigenous rice varieties with suitable test and aroma. Some of such quality cultivars from Assam are briefly discussed below:

1. Joha Rice: Aromatic rice of Assam is known as '*Joha*' in Colloquial, traditionally cultivated by the local farmers in a very small way. Joha rice exhibits several distinctive attributes that are superior over the widely known aromatic rice varieties like Basmati. Unlike long slender grains, Joha cultivars are short **(**< 4.7 mm**),** medium or bold grained with an L:B ratio below **3,** exhibiting approximately 1.4-times elongation during cooking and a tendency to break when overcooked**.** Basmati rice cooks fluffy due to high amylose content while Joha rice cooks sticky due to medium amylose and trace amount of amylopectin. It possesses a superfine kernel, unique aroma, better cooking properties, and excellent palatability. Joha rice is an intermediate between *Indica* and *Japonica* class of rice. The aromatic accessions originating from Assam, Manipur and Sikkim are belong to the *Indica* group. The aroma (fragrance) of Joha rice cultivars is due to the presence of a non-functional betaine aldehyde dehydrogenase 2 (BADH2), which leads to accumulation of 2-acetyl-1-pyrroline. Owing to its characteristic fragrance, superior grain attributes, and rich cultural legacy, Joha rice received the Geographical Indication (GI) status in 2016, acknowledging its uniqueness, authenticity and exclusive linkage to the agro-climatic conditions and age-old traditional cultivation practices of Assam. Assam's aromatic Joha rice is gaining global traction and recognition with recent significant exports to Vietnam. In early 2025, a 10,000 kg consignment of Joha rice was exported to Vietnam, sourced from farmers in Demow and Nitaipukhuri marking a key step in bringing this GI-tagged product to international markets, boosting farmer incomes and showcasing the region's unique agricultural potential.

2. Bora Rice: Waxy rice, a class of Sali rice known for stickiness has a very special place among the culinary landscape of Assam. During the cooking process of glutinous rice, it leads to characteristic sticky and cohesive texture due to the presence of high amount of amylopectin and low amount of amylose. Bora rice in general have high amount of amylopectin which is responsible for stickiness. Bora rice having low amylose content enables it to be used as an important ingredient in the preparation of many traditional dishes of Assam. It has versatile uses, right from preparation of puffed rice to rice beer, bamboo rice and pithas. They bear a unique texture along with its unique flavor. Rongili, Bhogali and Aghoni are the first high yielding variety (HYV)of waxy rice from Assam.

3. Chokuwa rice: Chokuwa rice varieties belong to traditional Sali rice varieties which are photosensitive and long duration (160 days) varieties exclusively grown in Assam. Low amylose rice varieties, locally termed as Chokuwa rice varieties, are preferred over the waxy varieties to prepare various products. Chokuwa or semi-waxy rice, a distinctive heritage rice characterized by its low amylose content, which makes it suitable for preparing the soft rice delicacy locally called *Komal Chaol*. Remarkably, Komal chaul (soft rice) is a whole grain, ready-to-eat product which needs no cooking and can be consumed after simply soaking in cold to lukewarm water. By Using of

traditional knowledge the rural people develops the methods and skills in preparing the products from Chokuwa rice varieties. Due to the uniqueness and regional significance it got GI tag in the year 2019.

4. Red Rice: In Assam, red-pericarped rice occurs across multiple rice growing ecologies, including Deepwater (Bao), Upland (Ahu) and in some Shallow/ Medium deep lowland. The coloration of these rice results from the high content of anthocyanins located in their pericarp layers, an antioxidant pigment in the bran of the rice grain. Compared to polished rice, red rice possesses highest nutritional value. Anthocyanin pigments are reported to be highly effective in lowering cholesterol levels in the human body and owing to their aldose reductase inhibitory activities, are beneficial for diabetic prevention. Bao rice is an indigenous rice of Assam, popularly grown as red rice or known deep water rice. It is rich in iron, protein, vitamins and other nutrients. There are several traditional varieties of Bao rice in Assam such as Neghari-Bao, Rangi-Bao, Amana Bao, Jul Bao, Dal- Bao etc. Traditional autumn red rice varieties such as Kolaguni, Kopouguni, Ronga Chokua, Ronga Dariya and winter rice (e.g.-Biroi) are some traditionally grown indigenous red rice varieties of Assam.

With the rising demand for red-kernelled rice in Western countries, international market demand has increased, and these traditionally low-yielding red-kernelled rice varieties are now fetching premium prices.

Conclusion:

The North-East region of India is a true **rice hub**, consisting a vast wealth of indigenous rice landraces renowned for their superior quality and distinct features. Aromatic and sticky rice varieties of this region are deeply rooted in the local cuisine and a wide range of delicious traditional rice products are prepared from these native cultivars. These landraces are not only valued for their quality and aroma but also symbolize the centuries of farmers' knowledge, cultural heritage, and genetic diversity. Acknowledging that "Rice is life", it is therefore essential to conserve these precious indigenous varieties and place greater emphasis on their organized cultivation and sustainable utilization. It is very important to preserve this invaluable genetic resource not only to safeguard the local/regional food traditions but also to ensure future food and nutritional security.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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WOMEN ACTIVITIES IN DEVELOPING ENTREPRENEURSHIP

Introduction

Entrepreneurship is the process of taking some risks with confidence to achieve a business objective. An entrepreneur is a person who starts an enterprise with a view to have some advantages of income. He searches for change and response to profit business. Thus, entrepreneurship is the attitude of mind to seek opportunities; take calculated risks and derive benefits by setting up a venture. There are four different types of entrepreneurship, which includes small, large, start-up and social entrepreneurship. Most of the developed countries in the world are already enjoying the fruits of the entrepreneurship development. In developing countries like India entrepreneurship has gained importance in the recent past. It is considered as the method of promoting self employment. Earlier the field of entrepreneurship was dominated by male persons of ancient time. Later woman entrepreneurship has been developed in India and has come into existence in 1970. Many women earlier worked in Xerox machine; STD booth, Banking service, Ticketing for Railway and Air passengers etc. Assamese women helped in transplanting of rice seeding in paddy field, Same way women in Assam helps in plucking tea leaf at regular interval. Thus entrepreneurship is considered to enhance the productivity capacity and size of the economy with the help of creativity and competitiveness (Zanjirchi et al, 2019). There are four different composite indices recorded viz. Female entrepreneurship index, Human inequality development index, Gender inequality index and Global index. The female entrepreneurship index.(FEI.) has been used as a proxy of women entrepreneurship (WE) and human development index (HDI) has been used as a proxy of economic development for our society. Women entrepreneurship play a significant role in producing jobs, wealth, poverty, reduction, human development, education, Health and nation's development, specially in developing countries. Without women, entrepreneurship, economic development in our society could not be achieved purposefully. In developed nations there are many expects donating to increase women entrepreneurship such as self fulfilment, creative skills, desire to independence, desire for wealth and power and social status.(Shah and Saurabh 2015.). Women has already shown their potentiality as astronauts, pilot, drivers, scientific activities in medical science, agriculture science, veterinary science, fishery services, engineering etc. The proper utilization of manpower ensured the growth, but in least developed countries; major portion of women workforce is either un-used or unnoticed; which could be a barrier for developmental issues. This barrier can be overcome with the encouragement and providing resources.(Vinay and Singh 2015.). Over the past two decades, female entrepreneurship evolution is very much inspiring and encouraging type.

Still, there is no any satisfactory contributions in women's business activities. As this contribution is in the smallest cluster of business. Approximately 81% of the women entrepreneurs has no workforce as compared to 75% of wholly privately maintained business in the USA. Female owned business obtained less than 1% of the business originated by men. Women entrepreneurs have not the same prospects as compare to men for rights, education, expressive carriers, political inspiration, and economic development. The gender inequality or discrimination occurs in all around the world. In such type of hurdle; women could perform up to their abilities as same in the case of men. This in-equality also exist in entrepreneurial activities of women owned business such type of disparity and inequality; women entrepreneurs could not fully contribute in the social and economic development of their respective fields. Thus, it is understood that the gender inequality is negatively associated with economic development.

So women entrepreneurs can mark their contribution as a significant tool to the economic development, social development and to the sustainable development for the future generation of the world. We can assume that successful woman entrepreneurs will play a model role for the future economic development of any country in this present day world. It is also true that the work activities and behaviour for women. Entrepreneurs are different for developed and developing countries, women entrepreneurship do not just earn income, but they can also create jobs for others. develop new ideas, thoughts, and drive social changes in our society.

In the developing country like India where gender gaps remain significant. Women entrepreneurship is crucial for promoting gender equality, reducing poverty and advancing overall social economic development. Entrepreneurship refers to the process where women start organize, manage and operate business on their own or togetherly. It can cover a wide range of businesses from small and local ventures to the large skill, technological start-ups. Women entrepreneurs work in sectors like agriculture, food, processing units, medical science, textile, education, music, veterinary sciences, fruits, and vegetable Sales etc. Many women lead companies, hire other women, increasing female workforce, participation and lowering unemployment in local and regional areas. Thus, Entrepreneurship empowers woman by giving them financial independence, confidence and decision making power. It allows women to have more control over their lives and engage in household and community decisions and achieve social recognition. Today in many places of our country, self help groups play a crucial role in promoting women entrepreneurship, specially in rural areas. These groups of people help in improving access to savings and loans, that enhance skills through training and encourage collective decision-making process of the society. With growing digitalization policy support and increased awareness; Women entrepreneurship has outstanding potential for growth in future. Women entrepreneurship is showing as an effective strategy to solve both the rural and urban poverty. The government of India through different policies and programmes are encouraging the Indian women to come forward and involve in different entrepreneur activities. The integrated rural development program(IRDP) training of rural youth for self employment(TRYSEM) development of women and children in rural areas(DWRCA). Entrepreneurship development programmes (EDP), Prime Minister Rojgar

Yojana(PMRY) are a very few examples of different programmes undertaken by planning commission, Government of India

From this above discussion, it is quite evident that women has to take responsibility in developing the entrepreneurship in any subject of their own. There is a direct relationship between the economic growth, poverty, reduction and women entrepreneurship. It has been correctly stated by our first Prime Minister, Pandit Jawaharlal Nehru ji, that when "women move forward, the family moves, the village moves and the nation also moves. The above discussion reveals that the women entrepreneurship are gaining recognition recently. Still, there is a long way to go for proper development.(Chavan and Murkute 2016). The role of women is vital in developing entrepreneurship for sustainable development in every aspects of business oriented fields. These entrepreneurship helping ultimately for creation of jobs for youth, developing communities and driving social progress in our society.

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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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Plant Tissue Culture–Based Approaches for Enhancing Diosgenin: Implications for Sustainable Agriculture

Abstract

Diosgenin is a biologically important steroidal sapogenin predominantly derived from Dioscorea species. It serves as a key starting material for the industrial synthesis of various steroidal pharmaceuticals. Conventional recovery of diosgenin from field-grown plants is constrained by several factors, including prolonged cultivation cycles, seasonal and environmental variability, inconsistent metabolite accumulation, and the rapid exhaustion of natural plant resources caused by excessive harvesting. Plant tissue culture techniques offer a reliable alternative for the sustainable and large-scale production of bioactive compounds under controlled and sterile conditions. In vitro systems such as callus cultures, cell suspension cultures, and hairy root cultures enable rapid biomass production and precise regulation of physiological and metabolic activities. Consequently, these culture platforms provide an effective approach for enhancing secondary metabolite synthesis through precursor supplementation, elicitor application, and optimization of culture conditions, including nutrient composition, photoperiod, and plant growth regulators. This paper indicates that the application of biotic and abiotic elicitors, precursors, and optimal growth conditions can enhance the production of diosgenin in plant tissue culture systems. Unlike field-grown plants, in vitro production systems provide a continuous, uniform process for metabolite production that is not affected by seasonal changes or environmental variations. Therefore, from the point of agricultural and environmental sustainability, in vitro diosgenin production is a sustainable approach to agricultural development, as it conserves agricultural land, prevents the overexploitation of wild medicinal plants, and supports biodiversity conservation. Additionally, these technologies offer new paths for the development of Agri-biotechnology and the pharmaceutical industries by providing a scalable, eco-friendly and economically feasible approach to the production of high-value phytochemicals.

Keywords**:** Diosgenin, *Dioscorea* spp., Plant tissue culture, Secondary metabolites, Sustainable agriculture

1. Introduction

Medicinal plants, which produce bioactive secondary metabolites, play an important role in agricultural and medicinal sciences. Given its wide range of medicinal properties, Diosgenin, being a steroidal sapogenin obtained chiefly from the *Dioscorea* species, has assumed ever-increasing importance (Adeyemi & Akanji, 2011). In addition to having antioxidant, antidiabetic, and cardioprotective effects, it is also an important precursor in the semi-synthesis of corticosteroids, contraceptive agents, and anti-inflammatory agents (Siddique et al., 2020). *Dioscorea* plants growing in fields are conventionally used to extract Diosgenin from tubers and rhizome tissues.

However, the low growth rate, low production levels of the metabolites, seasonal availability, and stress are major limitations in the conventional cultivation of Dioscorea (Pandey et al., 2015). In addition, the biodiversity of medicinal plants is greatly impacted by the overuse of wild Dioscorea resources, resulting in habitat destruction and degradation (Bhatt et al., 2018). Due to these limitations, approaches that ensure both ecological sustainability and economic viability are required. Tissue culture methods can help in the effective use of resources, conservation of medicinal plant germplasm, and value addition through biotechnology-based agri-enterprises in the context of sustainable agriculture (Singh et al., 2019).Thus, diosgenin production through tissue culture techniques can aid the pharmaceutical sector and complement conventional agriculture. This article discusses strategies to maximize diosgenin production through plant tissue culture techniques and their significance in sustainable agricultural development.

1. Diosgenin and Its Agricultural Significance

Conventional Cultivation
(Low yield, seasonal, overharvesting)
↓
Need for Sustainable Alternatives
↓
Plant Tissue Culture Systems
(Callus, Cell suspension, Hairy roots)
↓
Elicitation & Metabolic Enhancement
↓
Enhanced Diosgenin
↓
Sustainable Agriculture & Bioeconomy

Diosgenin is primarily present in the underground parts of *Dioscorea* species and is synthesized through steroidal biosynthetic pathways. However, Diosgenin availability from field cultivation is inconsistent due to substantial variability in its composition across species Diosgenin is primarily present in the underground parts of Dioscorea species and is synthesised via steroidal biosynthetic pathways. However, Diosgenin availability from field cultivation is inconsistent due to substantial variability in its composition across species, varieties, and growing conditions (Pandey et al., 2015). As a result, there has been increasing interest in alternative methods for producing diosgenin to meet rising industrial demand.

2.1 In Vitro Culture Systems for Diosgenin Enhancement

If callus cultures established from explants such as tubers, leaves, or nodes are grown on optimised media, they can produce diosgenin (Jain & Gupta, 2005). Callus cell suspension cultures are amenable to scale-up in bioreactors and can continuously produce metabolites (Rao & Ravishankar, 2002).

Hairy root cultures induced by Agrobacterium rhizogenes are highly promising for the production of secondary metabolites. Compared with untransformed tissues, hairy root cultures have an elevated biosynthetic potential, high growth rates, and genetic stability (Giri & Narasu, 2000; Kolewe et al., 2008).

2.2 Elicitation and Metabolic Manipulation

Among the techniques used to enhance the in vitro production of secondary metabolites is elicitation. Diosgenin production can be significantly improved by both biotic and abiotic elicitors, such as yeast extracts, methyl jasmonate and salicylic acid (Namdeo, 2007; Roy et al., 2012). The production of metabolites can be further improved by precursor feeding and carbon/nitrogen sources (Matkowski, 2008). The key enzymes for diosgenin production can now be controlled through recent developments in metabolic engineering and genome editing (Siddique et al., 2020).

2.3 Contribution to Sustainable Agriculture

The tissue culture-based diosgenin production technique supports sustainable agriculture because it requires less land, fewer agrochemicals, and helps maintain wild medicinal plants (Karuppusamy, 2009). The use of in vitro techniques in agri-biotech platforms can improve the value chain of medicinal plants.

Fig 01. Strategic inputs used to maximize bioactive yields in *Dioscorea* species.

Table 01: Plant tissue culture strategies and their effects on diosgenin production in *Dioscorea* spp.

S. No	Strategy	Specific Method	Impact on Diosgenin Production	Reference
1	Elicitation	Treatment with Salicylic Acid (SA) or Methyl Jasmonate (MeJA).	SA at 200 µM significantly boosted yields in *D. deltoidea* shoot cultures.	Nazir et al. (2021)
2	Precursor Feeding	Addition of β-sitosterol or squalene to the medium.	β-sitosterol (200 µM) achieved maximum diosgenin content (1.006% DW).	Nazir et al. (2021)
3	Fungal Elicitors	Oligosaccharides from endophytic *Fusarium oxysporum*.	Achieved a 12.38-fold increase in *D. zingiberensis* cell suspension cultures.	Zhou et al. (2006)
4	Hairy Root Culture	*Agrobacterium rhizogenes* mediated transformation.	Up-regulation of rate-limiting genes leads to high-purity, scalable production.	Shah & Lele (2012)
5	Low-Cost PTC	Use of commercial bleach and PVP browning control.	Reduced equipment costs by 95%, enabling community-based sustainable farming.	Sookruksawong (2026)

2. Conclusion

Plant tissue culture provides a robust platform for the sustainable enhancement of diosgenin production in Dioscorea species. In vitro systems, including callus, cell suspension, and hairy root cultures, enable rapid biomass generation and uninterrupted metabolite synthesis, bypassing the challenges of conventional cultivation. The strategic use of elicitors and optimized growth environments further increases diosgenin yield, demonstrating the potential of tissue culture–based technologies. These approaches lessen the exploitation of natural plant resources and promote biodiversity conservation. Moreover, they contribute to sustainable agriculture through improved land utilization and resource management.

3. Future Perspectives

Future research should focus on the scale-up of in vitro diosgenin production using bioreactor-based culture systems to facilitate commercial application. Advances in molecular biology, metabolic engineering, and biosynthetic pathway manipulation are expected to play a crucial role in further enhancing diosgenin yield. Strengthened collaboration between plant scientists, biotechnologists, and industrial partners will be essential to translate laboratory-level success into industrial processes. Addressing challenges related to cost efficiency, scalability, regulatory approval, and technology transfer will be critical for the widespread adoption of tissue culture–based diosgenin production systems within sustainable agricultural frameworks.

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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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THE DIGITAL PLANT DOCTOR: AI-DRIVEN DIAGNOSTICS FOR A SUSTAINABLE FUTURE FOR INDIAN SMALLHOLDERS

Abstract

In the era of climate-induced agricultural volatility, the traditional methods of plant disease management are proving insufficient. This article explores the transformative potential of Artificial Intelligence (AI) and Computer Vision in bridging the diagnostic gap for Indian smallholders. By aligning with the United Nations Sustainable Development Goals (SDGs), specifically Zero Hunger (SDG 2) and Responsible Consumption (SDG 12), AI-driven diagnostics offer a pathway to reducing pesticide dependency, increasing yields, and securing the livelihoods of millions.

The Silent Crisis: Why Traditional Diagnostics are Failing

Agriculture in India is at a crossroads. Despite being a global leader in the production of staples like rice, wheat, and pulses, the sector loses approximately 15–25% of its potential output to pests and diseases annually. In a country where over 80% of farmers are small and marginal, a single unchecked outbreak can mean the difference between subsistence and debt (Anonymous, 2025)

The primary bottleneck is the Extension Gap. The ratio of agricultural extension officers to farmers in India is starkly imbalanced. When a pathogen strikes—be it the Wheat Rust in the north or the Yellow Mosaic Virus in the pulse-growing belts of the south—the farmer often lacks immediate access to a qualified plant pathologist (Niaz *et al.* 2025). This lack of "expert eyes" leads to:

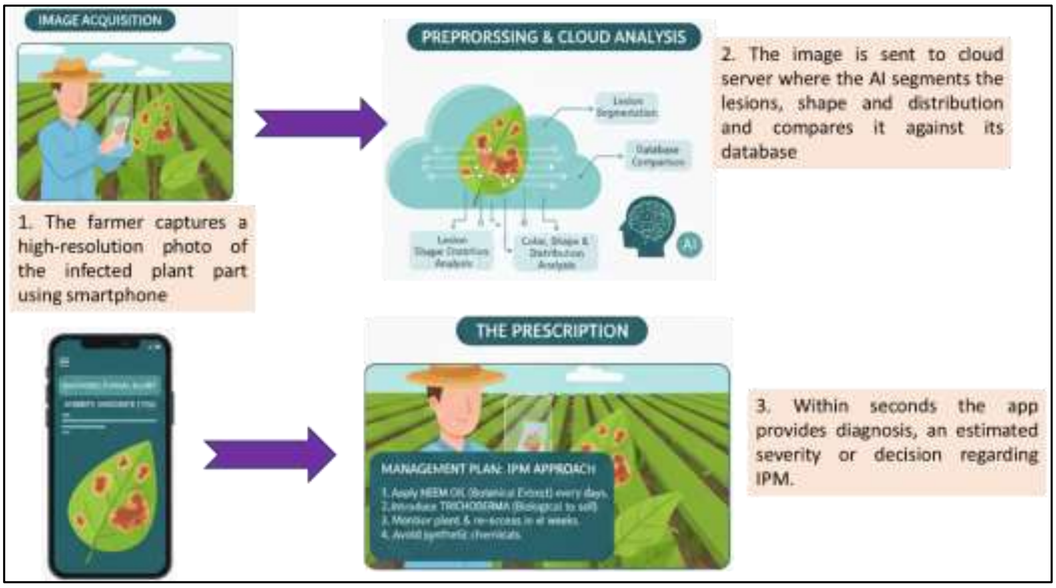

Figure 1 : Workflow of AI technology

1. **Late Diagnosis:** Pathogens are often identified only after they have reached the "epidemic" stage, where chemical intervention is both expensive and less effective.
2. **Misdiagnosis:** Abiotic stresses (like salinity or drought) are frequently mistaken for biotic stresses (fungal or bacterial infections), leading to the application of unnecessary fungicides.[3]
3. **Prophylactic Spraying:** A "just-in-case" mentality that saturates the soil and water table with toxins.

The Innovation: The Mechanics of AI-Driven Pathology

The "Digital Plant Doctor" is not a single app but an ecosystem of technologies. At its core lies Deep Learning, specifically Convolutional Neural Networks (CNNs) (Barbedo et al. 2022). These are mathematical models inspired by the human visual cortex, designed to recognize patterns in images.

How the "Doctor" Learns

To build a reliable AI, researchers feed the model millions of labelled images. For an Indian context, this means training the AI on diverse data:

- **Rice (Oryza sativa):** Identifying Blast (*Pyricularia oryzae*), Brown Spot (*Helminthosporium oryzae*), and Bacterial Leaf Blight.
- **Cotton (Gossypium):** Early detection of Pink Bollworm damage and Leaf Curl Virus.
- **Potato/Tomato:** Distinguishing between Early and Late Blight, which require vastly different management strategies.

The Workflow

1. **Image Acquisition:** The farmer captures a high-resolution photo of the infected plant part using a basic smartphone.
2. **Preprocessing & Cloud Analysis:** The image is sent to a cloud server (or processed locally on the edge) where the AI segments the lesion, analyses the colour, shape, and distribution, and compares it against its database.
3. **The Prescription:** Within seconds, the app provides a diagnosis, an estimated severity score, and a management plan. Importantly, modern apps now prioritize Integrated Pest Management (IPM), suggesting botanical extracts (like Neem oil) or biological controls (like *Trichoderma*) before recommending synthetic chemicals.

Strategic Alignment with the SDGs

The true value of AI in plant pathology is measured by its contribution to global sustainability targets.

SDG 2: Zero Hunger through Yield Stability

By 2050, India will need to feed nearly 1.7 billion people. We cannot achieve this through land expansion; we must achieve it through loss prevention. AI diagnostics provide a "safety net," allowing for precision agriculture that stabilizes the national food supply.

SDG 12: Responsible Consumption (The Pesticide Pivot)

India is one of the largest consumers of pesticides in Asia. However, much of this use is inefficient. AI-driven precision pathology ensures that chemicals are used only where and when needed. Data from the India-AI Impact Report (2025) suggests that precision application can reduce the environmental "chemical load" by up to **35%** without compromising yield.

SDG 15: Life on Land (Protecting Soil Microbiomes)

Over-application of fungicides disrupts the delicate balance of soil microbes. By reducing chemical runoff, AI diagnostics help preserve the "living soil," which is essential for long-term agricultural viability.

Figure 2: Smartphone is now a "Digital Plant Doctor", bridging the gap between science and field

Case Study: The Rice Blast Sentinel

In 2025, a pilot project in the Guntur district of Andhra Pradesh utilized AI-enabled drones and handheld devices to monitor Rice Blast. Farmers who acted on AI alerts in the "initial lesion" stage saved an average of ₹4,500 per acre in input costs and saw a 12% higher yield compared to neighbours using traditional spraying schedules (Mrinal, 2025).

The Indian Ecosystem: AgriStack and IndiaAI

India is uniquely positioned to lead this revolution due to its Digital Public Infrastructure (DPI).

- **AgriStack:** A collection of digital databases that provide every farmer with a "Digital Identity," linked to their land records. This allows the "Digital Doctor" to know the soil type and weather history of the specific farm, making the diagnosis even more accurate.
- **Bhashini Mission:** Language is no longer a barrier. AI diagnostics are now being integrated with real-time translation, allowing a farmer in rural West Bengal to hear a diagnosis in Bengali while the scientific backend operates in English.

Challenges and the Path Forward

While the potential is vast, hurdles remain:

1. **Data Diversity:** A model trained on European potatoes may fail on Indian varieties due to differences in humidity and leaf morphology. We need "hyper-local" datasets.
2. **Internet Connectivity:** Many "shadow zones" in rural India require Edge-AI—models that can run on a phone without an internet connection.
3. **Trust:** Farmers are rightfully skeptical of "black box" technology. Demonstrations through Krishi Vigyan Kendras (KVKs) are essential.

Conclusion

The integration of AI into plant pathology is more than a technological upgrade; it is a fundamental shift in how we relate to the land. It moves us away from a war against nature toward a system of "intelligent co-existence." As India moves toward its goal of becoming a $5 trillion economy, the "Digital Plant Doctor" will be a cornerstone of a resilient, sustainable, and *Atmanirbhar* (self-reliant) agricultural sector.

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Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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MEDICINAL PLANTS AS A SOURCE OF HIGH-VALUE BIOACTIVE COMPOUNDS: OPPORTUNITIES FOR SUSTAINABLE AGRICULTURE

Abstract

Medicinal plants are valuable sources of bioactive compounds used in various sectors, including pharmaceuticals, cosmetics and agriculture. Bioactive compounds, such as alkaloids. Flavonoids, terpenoids, phenolics, and glycosides have been shown to exhibit antioxidant, antimicrobial, anti-inflammatory, and anticancer properties. The rising demand for plant-based products, along with concerns about environmental sustainability, soil degradation, and farm income, has led to renewed interest in medicinal plants as alternative, high-value crops. Unlike other conventional crops, medicinal plants are known to require less chemical use, can be grown on marginal lands and are suitable for organic and low-input agricultural systems. The use of medicinal plants in agriculture offers opportunities for crop diversification, value addition, increased farmer income and biodiversity conservation. This article discusses the significance of medicinal plants as sources of valuable bioactive compounds and their role in promoting sustainable agriculture.

Keywords: Medicinal plants, Bioactive compounds, Sustainable agriculture, Crop diversification, Value addition

1. Introduction

Medicinal plants have been used since ancient times for the preservation and treatment of diseases and remain an important source of modern medicine (Dixon, 2001; Saxena et al., 2013). Many modern medicines are derived from plant-based bioactive compounds, which emphasises the importance of medicinal plants in modern healthcare systems (Bourgaud et al., 2001). These bioactive compounds, also known as secondary metabolites, are responsible for the medicinal properties of medicinal plants (Kintzios, 2002). Modern agriculture is challenged by factors such as the overuse of agrochemicals, soil degradation, climate change, and fluctuations in agricultural income (Singh et al., 2019). In this scenario, medicinal plants can serve as an alternative crop that supports economic and ecological sustainability (Singh & Sharma, 2015). The growing demand for herbal medicine, nutraceuticals and natural cosmetics has further increased the agricultural significance of medicinal plants (Karuppusamy, 2009; Pandey et al., 2015).

Uncontrolled collection of medicinal plants from their habitats has led to the depletion of wild populations and loss of biodiversity (Bhatt et al., 2018). The cultivation of medicinal plants promoted by this article will reduce dependence on natural habitats while ensuring a steady supply of raw materials (Singh & Sharma, 2015). Therefore, integrating medicinal plants into sustainable agricultural systems offers both conservation and livelihood benefits (Singh et al., 2019).

2. Bioactive Compounds and Agricultural Importance

Medicinal plants produce a diverse array of bioactive compounds, including alkaloids, flavonoids, terpenoids and glycosides, which have immense pharmacological and economic value (Bourgaud et al., 2001; Matkowski, 2008). Alkaloids are widely used for pain relief and cancer treatment, while flavonoids and phenolics are valued for their antioxidant and anti-inflammatory properties (Adeyemi & Akanji, 2011; Saxena et al., 2013). Terpenoids and essential oils are used extensively in pharmaceuticals, cosmetics and botanical pesticides (Dixon, 2001). From an agricultural perspective, medicinal plants offer several advantages. They can be grown using low-input or organic farming practices and can thrive on marginal lands (Ncube et al., 2012; Singh & Sharma, 2015). Their integration into intercropping and agroforestry systems enhances land use efficiency and sustainability (Singh et al., 2019).

3. Value Addition and Role in Sustainable Agriculture

The economic potential of medicinal plants is not only in their cultivation but also in value addition through processing, extraction, formulation, and packaging (Karuppusamy, 2009; Pandey et al., 2015). Value addition increases farmer income and provides opportunities for rural entrepreneurship (Singh & Sharma, 2015). Organised value chains and quality assurance systems are required to maximise economic benefits (Saxena et al., 2013).

Medicinal plant cultivation supports sustainable agriculture by reducing the use of synthetic agrochemicals, increasing biodiversity, and supporting ecosystem services (Bhatt et al., 2018; Singh et al., 2019). The use of plant-derived bioactives as botanical pesticides and bio-stimulants further supports eco-friendly farming practices (Ncube et al., 2012; Karuppusamy, 2009). Crop diversification using medicinal plants also helps in building climate change resilience and reduce economic risks for the farmers (Singh et al., 2019).

Secondary metabolite accumulation in plant tissue culture is strongly influenced by culture medium composition, plant growth regulators, light conditions, and elicitation strategies. Although Murashige and Skoog (MS) medium supports rapid biomass growth, modified media with altered nutrient strength or carbon sources often enhance secondary metabolite production by inducing mild metabolic stress (Murashige & Skoog, 1962; Verpoorte et al., 2002). Similarly, optimized auxin–cytokinin ratios promote metabolic differentiation and improve steroidal sapogenin biosynthesis in *Dioscorea* cultures (George et al., 2008).

Table 01: Major culture factors affecting secondary metabolite production under in vitro conditions

S. No	Factor	Key Role in Metabolite Production	Outcome	Reference
1	Culture medium (MS vs. modified)	Nutrient stress and carbon optimization	Enhanced sapogenin accumulation	Murashige & Skoog, 1962; Verpoorte et al., 2002
2	Plant growth regulators	Auxin–cytokinin balance	Improved metabolic differentiation	George et al., 2008
3	Light intensity & photoperiod	Regulation of sterol biosynthetic enzymes	Increased metabolite yield	Taiz et al., 2015
4	Elicitors	Stress-induced secondary metabolism	Amplified diosgenin production	Namdeo, 2007
5	Biomass – metabolite relationship	Shift from primary to secondary metabolism	Yield independent of biomass	Rao & Ravishankar, 2002

Light intensity and photoperiod regulate sterol pathway enzymes and carbon flux, with moderate light conditions favoring metabolite accumulation (Taiz et al., 2015). The effectiveness of elicitors such as methyl jasmonate and salicylic acid further depends on optimized basal growth conditions (Namdeo, 2007). Importantly, metabolite production does not always correlate with biomass accumulation, as higher yields often occur during later growth phases (Rao & Ravishankar, 2002).

Selection of Medicinal Plant Species
↓
Cultivation under Sustainable Farming
↓
Harvesting & Primary Processing
↓
Extraction / Value Addition
↓
Pharma / Nutraceutical / Agri-Inputs
↓
Sustainable Agriculture & Livelihood Support

Fig 02. Integration of medicinal plants into sustainable agriculture

4. Conclusion

Medicinal plants are important agricultural resources because they can synthesise valuable bioactive compounds with diverse uses. (Bourgaud et al., 2001; Dixon, 2001). The use of medicinal plants in agricultural systems promotes crop diversification, income and stability (Singh & Sharma, 2015; Singh et al., 2019). By reducing reliance on wild plants, cultivating medicinal plants promotes biodiversity conservation (Bhatt et al., 2018; Pandey et al., 2015). Improving cultivation practices, value chains, and farmers' knowledge will be vital for the optimal utilisation of medicinal plants in sustainable agriculture (Karuppusamy, 2009; Saxena et al., 2013).

5. Future Perspectives

The future of sustainable agriculture increasingly depends on integrating medicinal plants into mainstream farming systems. Greater emphasis on standardised cultivation practices, quality planting material, and value chain development will enhance the consistent production of high-value bioactive compounds. Advances in agronomic management, processing technologies, and market linkages are expected to improve farmer participation and profitability. Policy support for farmer training and industry collaborations will play a crucial role in scaling up medicinal plant-based agriculture, contributing to biodiversity conservation, climate-resilient farming, and the growth of plant-based bioeconomies.

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Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

ARTICLE ID: 23

184 NEW CROP VARIETIES AND THE FUTURE OF INDIAN FARMING

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Introduction: Seeds as the Foundation of Agricultural Change

Agriculture begins with a seed. Every improvement in yield, resilience, nutrition, or income ultimately traces back to the genetic potential locked inside it. In January 2026, India took a major step in strengthening this foundation with the release of **184 new crop varieties** by the **Indian Council of Agricultural Research (ICAR)** under its national varietal release system.

This was not a routine announcement. It came at a time when Indian agriculture is under pressure from climate change, soil degradation, pest resistance, shrinking landholdings, and rising input costs. The newly released varieties are designed to address these challenges simultaneously—by increasing productivity, stabilizing yields under stress, improving nutritional quality, and reducing production risks for farmers.

These 184 varieties span **25 crops** and are tailored for India's diverse agro-climatic regions, including irrigated plains, rainfed drylands, coastal belts, flood-prone areas, and heat-stressed zones. Together, they represent years of coordinated scientific work across ICAR institutes, state agricultural universities, and partner seed organizations.

India's Crop Improvement System: How These Varieties Are Developed

India follows one of the world's most rigorous public crop improvement systems. New varieties are not released based on laboratory results alone. Each promising breeding line undergoes **multi-location, multi-year field trials** across different agro-climatic zones. Only varieties that consistently outperform existing checks in yield, stability, and adaptability are recommended for release.

ICAR coordinates this effort through national crop research networks. Scientists evaluate traits such as yield potential, maturity duration, resistance to pests and diseases, tolerance to drought, flood or salinity, and grain or fiber quality. After technical scrutiny, varieties are notified for cultivation in specific regions.

Over the last decade, this system has released more than 3,000 varieties. The latest set of 184 varieties reflects a clear shift in breeding priorities—from maximizing yield alone to **balancing productivity with climate resilience, nutritional value, and sustainability**.

Crop Coverage: What Farmers Are Getting

The 184 varieties cover crops that form the backbone of Indian agriculture.

Rice and Maize: Securing Staple Food Supplies

Rice leads the list with **60 new varieties**, followed by **50 maize varieties**. These cereals are critical for national food security.

The new rice varieties include types suited for:

- irrigated high-productivity systems
- rainfed uplands
- flood-prone and waterlogged areas
- short-duration cropping systems

Several varieties are tolerant to submergence or moisture stress, making them suitable for eastern and northeastern India where floods and erratic rainfall are common. Others are bred for higher yield and better grain quality in irrigated regions.

Maize varieties include both hybrids and open-pollinated types. They are targeted for diverse uses—grain, feed, and fodder—and for regions ranging from irrigated belts to rainfed plateaus. Improved stress tolerance and stronger root systems help stabilize maize yields during dry spells.

Millets and Sorghum: Climate-Smart Crops for the Future

A significant share of the new releases comes from **millets and sorghum**, including pearl millet, finger millet, little millet, proso millet, and sorghum. These crops are naturally hardy and require fewer inputs, making them ideal for dryland and marginal environments.

The new millet varieties offer:

- higher grain yield than traditional landraces
- improved tolerance to heat and moisture stress
- better grain size and uniformity

Beyond yield, millets contribute to **nutritional security**, providing higher levels of fiber, minerals, and micronutrients. Their promotion aligns with national efforts to diversify diets and make farming more resilient to climate variability.

Pulses: Strengthening Protein Security

Six new pulse varieties were released, including pigeon pea, green gram, and black gram. Pulses are vital for both nutrition and soil health due to their nitrogen-fixing ability.

The new pulse varieties are characterized by:

- shorter maturity duration
- better tolerance to drought and pests
- more uniform pod and grain size

These traits help farmers reduce crop failure risks in rainfed systems while improving productivity. Even modest yield gains in pulses can significantly impact farm income due to strong market demand.

Oilseeds and Fodder: Supporting Farm Economics

Thirteen oilseed varieties—covering mustard, groundnut, sesame, sunflower, safflower, and castor—address India's long-standing dependence on edible oil imports. Higher oil content, better adaptability, and disease resistance are key features of these releases.

Eleven new fodder varieties strengthen the livestock sector by improving availability of quality green fodder. Better fodder productivity directly translates into higher milk yields and more stable income for mixed farming households.

Cotton, Sugarcane, and Commercial Crops

Cotton accounts for **24 varieties**, most of them Bt hybrids. These offer improved resistance to bollworms and better fiber quality, particularly in rainfed cotton belts where pest pressure is high.

Six new sugarcane varieties focus on higher sugar recovery, better ratooning ability, and tolerance to climatic stress. Improved jute and tobacco varieties cater to specific regional and industrial needs.

Agro-Climatic Targeting: Matching Varieties to Regions

India's agricultural diversity demands location-specific solutions. The 184 varieties are carefully mapped to different agro-ecological situations:

- **Irrigated plains** benefit from high-yield cereals and oilseeds
- **Rainfed regions** receive drought-tolerant millets, pulses, and maize
- **Flood-prone areas** gain submergence-tolerant rice
- **Coastal and saline soils** are addressed through tolerant rice, oilseed, and sugarcane varieties
- **Tribal and hill regions** receive improved nutri-cereals suited to low-input systems

This targeting increases the likelihood of success at the field level and reduces the risk of crop failure.

Farmer Adoption: From Research Plots to Fields

For farmers, a new variety matters only if it performs reliably and generates visible benefits. Adoption depends on three key factors:

1. **Seed availability** – timely multiplication and distribution
2. **Demonstration and trust** – farmers adopt what they see working nearby
3. **Economic advantage** – higher yield, lower risk, or better price

Early demonstrations of some varieties already show encouraging results, particularly in rice, cotton, millets, and pulses. Farmers report more stable yields under stress and reduced pest damage.

However, scaling adoption requires strong extension support. Field demonstrations, training programs, and clear region-specific recommendations will determine how quickly these varieties reach widespread use.

Potential Impact on Indian Agriculture

If adopted at scale, the 184 new crop varieties can generate multiple long-term benefits:

- higher and more stable food production
- improved resilience to climate extremes
- reduced dependence on imports, especially edible oils
- better nutrition through diversified diets
- increased income stability for small and marginal farmers

Unlike short-term inputs, improved varieties deliver benefits year after year, making them one of the most cost-effective investments in agriculture.

Conclusion: Seeds That Shape the Future

The release of 184 new crop varieties marks a decisive step in strengthening Indian agriculture at its genetic core. These varieties are not just scientific achievements; they are practical tools designed for real fields, real farmers, and real challenges.

By combining productivity with resilience and nutrition, ICAR's latest releases offer a pathway toward a more stable, sustainable, and inclusive agricultural future. Their true success will be measured not in laboratories or reports, but in farmers' fields—where better seeds can mean better harvests, better livelihoods, and greater food security for the nation.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 24

LEDS: AN ALTERNATIVE TO ARTIFICIAL LIGHTS IN PLANT GROWTH FACTORIES

Introduction

Farming practices are rapidly shifting from sustenance-based farming to high-value crop production in recent times. Horticulture in urban and peri-urban areas is a topic in focus for upcoming years; as the land resources are rapidly shrinking and countryside areas are being converted to industrial areas gradually. Thus, there needs to be more focus on practices based on vertical farming. These practices utilize lesser space and can be executed on a small scale as well. People have already started cultivated of micro greens, herbs and vegetables in urban areas by using innovative techniques to save space. One of the major components in urban horticulture is artificial lighting system. Plants utilize light under natural conditions in the form of photosynthesis, to carry out essential physiological functions, primarily responsible for growth and development. Light resctriction is a primary hindrance during cultivation under enclosed/semi-outdoor areas. Traditionally, artificial light sources like HPS lamps, fluorescent bulbs have been utilized for providing primary/supplementary lighting. However, due to certain limitations such as overheating, high utilization of electricity and lack of customization available, people are rapidly shifting towards LED lights as the illumination source for several plants. This article explains LED lights and several advantages it can offer for plants.

LEDs as light source for plants

LEDs (Light Emitting Diodes) are a recent advancement and one of the key facets of climate smart agriculture. Among precision farming and protected cultivation sector, these can also be grouped as a significant source of energy efficient lights. All the LEDs are technically a semiconductor device; enabling modulation of light specrum composition in alignment with photoreceptors in plants, to enhance morpho-physiological processes in plants **(Yeh and Chung, 2009)**. Numerous studies have indicated LEDs as an efficient, energy saving technology as opposed to conventional sources for artificial light, e.g. high pressure sodium lamps. With a life span of 30,000- 50,000 hours, plants can be conveniently kept in close proximity to LEDs as they provide a greater luminous flux with less radiant heat production. **(Barta et al., 1992; Tennessen et al., 1994)**. They also provide a cooling effect to the crop canopy, thus providing an optimal microclimate for overall plant development. Using LEDs makes it viable to modulate the framework of light spectrum and quality of light delivered to the different plant species in a digitally operated and energy-efficient manner **(Lin et al., 2013)**.

Over the years, LEDs have been tested under several crops like lettuce, tomato, and particularly short-day plants like chrysanthemum. Other than greenhouses, LEDs have also been used in growth chambers and in tissue culture for providing the required wavelength of light spectrum. Red, blue, green and a mixture of different colour combinations have been used for different crops and have varying effects depending on crop and species.

LEDs: Significance and Advantages

Energy is an important aspect of crop production in a controlled environment which accounts for 20-30% of the total cost of production (Brumfield, 2007). Supplemental lighting is of prime importance in areas where the photoperiod constantly fluctuates, and ambient illumination is insufficient for plant development. HPS lamps are the most common and traditional source of lighting in this scenario; even though a generous amount of heat is produced (>200°C) during the illumination (Opdam et al., 2005). This radiant heat has a negative and irreversible effect on the plants. Hence, always a distance of >2 m is adjusted between crop and the lamps. This feature of HPS lamps has resulted in their limited use in future climate control projects (Ieperen et al., 2008).

On the other hand, LEDs consist of active heat sinks, which assist in the passage of waste heat generated. This component facilitates placing them on top of the crop canopy for several hours without any potential damage or stress to the plant **(Bourget, 2008).** LED emits light of a specific wavelength, which can be broadband (white) or narrow spectrum (colored) **(Nanya et al., 2012)**.

LEDs offer several advantages over traditional lighting sources **(Massa et al., 2008):**

1. Light-weight, compact, and easy to install, without heavy cables.
2. Temperature stability in greenhouse and growth chambers, with little heat stress.
3. Up to 70% energy savings compared to traditional lighting sources.
4. Electronic dimmer function allows manipulation of light intensity in accordance with different crop species.
5. LED lights in red spectrum have the highest RQE (Relative Quantum Efficiency), providing maximum photosynthesis rate.
6. Blue lights have 75% efficiency compared to red lights.

Light spectra and their effects

The use of artificial light sources for plants dates to 1991 when lettuce was first grown under blue and red fluorescent lamps. Red light (610-720 nm) promotes photosynthesis, while blue light (400–500nm) helps chlorophyll and chloroplast development (Fig. 1 & Fig.2), closure and opening of stomata and photo-morphogenesis **(Akoyunoglou & Anni, 1984; Saebo et al., 1995)**.

LEDs in Growth Chambers

In recent years, growth chambers have become an essential aspect of CEA (Controlled Environment Agriculture). They are enclosed spaces in an indoor environment under LED lights with plants placed nearby. LEDs have varying physiological and morphological influences on several crops, depending on species and cultivars. Different combinations of light spectrum at different intensities have shown results on several plant species **(Ouzounis et al., 2015)**.

LEDs in Greenhouse

The cumulative quantity of Photosynthetically Active Radiation (PAR photons) (400-700 nm) received over a certain region during a 24-hour period is termed as Daily Light Integral (DLI) (Bula et al., 1991). These additional light sources in greenhouses function as an instrument in order to accentuate the DLI of crop plants, particularly ones that need longer light duration for their development. The use of LEDs in greenhouses provides a vast scope from both research and commercial aspects.

Conclusion

Supplementary/artificial lighting systems have been used as early as 1990s for manipulating photoperiodic functions and/or extending daylength. In recent times, different spectral components of light can be manipulated in various combinations to achieve desired results for greenhouses and vertical greening systems.

Different spectral components and their combinations have varying effects on growth and physiological functions. Red light seems to reduce photosynthetic efficiency of plants indicating lower total chlorophyll value but an increased stomatal size. Vegetative characteristics like stem length and leaf area tend to decrease while flowering characteristics like bud length, bud outgrowth and flower size tend to increase. Research has shown that blue light can lead to greater plant height and longer internodes, although this may result in fewer leaves and thinner leaf structures when exposed to higher intensities. It also responds positively for photosynthetic capacity as chlorophyll content and stomatal conductance tend to increase. With respect to flowering parameters, it reports an early bud and flower induction.

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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 25

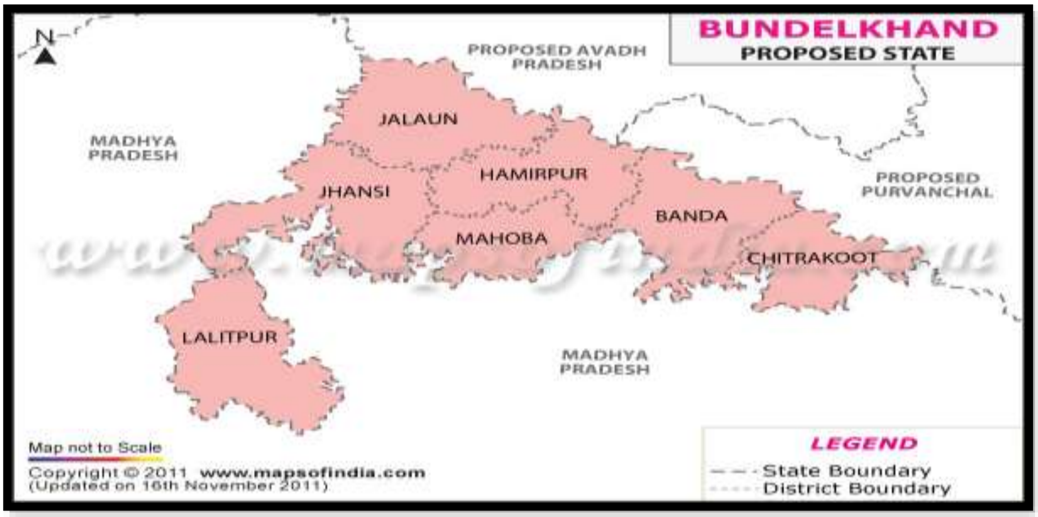
OILSEED CULTIVATION UNDER CLIMATIC STRESS IN BUNDELKHAND: TRENDS IN GROUNDNUT AND RAPESEED–MUSTARD

Abstract

Bundelkhand, located in the southern part of Uttar Pradesh, is one of the most climate-vulnerable agricultural regions of India. Agriculture in the region is predominantly rain-fed, making cropping decisions highly sensitive to environmental stress. Uttar Pradesh area of Bundelkhand contributes 5% in state economy and 31.1 in agriculture and allied share in economy and 82.1 in crops share (%) in agriculture and 17.9 livestock share in agriculture.(Estimates based on National accounts data, MoSPI, GoI). However, this area faces persistent challenges due to its rugged terrain, erratic weather patterns, and limited water resources. Among the key crops cultivated here, oilseeds play a vital role in the local economy, providing essential edible oils and supporting livelihoods for millions of farmers.

Introduction

Bundelkhand region in Uttar Pradesh comprises seven districts: Jhansi, Jalaun, Lalitpur, Hamirpur, Mahoba, Banda, and Chitrakoot. Agriculture here is predominantly rainfed, with average annual rainfall of 800–1000 mm, but highly erratic and prone to severe droughts. Oilseeds are integral to Bundelkhand's farming system, occupying a significant portion of the cultivable land. Groundnut, a kharif (rainy season) crop, thrives in well-drained sandy soils and requires adequate monsoon rainfall for optimal growth. Rapeseed-mustard, on the other hand, is a rabi (winter) crop that benefits from cooler temperatures and residual soil moisture post-monsoon. Together, these crops account for a substantial share of India's oilseed production, with Uttar Pradesh being a major contributor.



For groundnut, the area under cultivation in Uttar Pradesh has declined significantly over the decades, from around 3.29 lakh hectares in the mid 1960s to less than 1 lakh hectares by 2013-14, with a compound annual growth rate of -3.53%. This trend is mirrored in Bundelkhand, where local conditions exacerbate the issue. Rapeseed-mustard, while showing some resilience with modest growth in area (around 2.94% annually in recent analyses), (Kumar et al., 2024). still suffers from low yields, averaging just 763 kg per hectare in the region far below the national figure. Production figures follow suit, with groundnut output dropping due to shrinking acreage and variable yields, while rapeseed-mustard production has experienced instability despite occasional upticks.

Trends in Area and Production of Groundnut and Rapeseed-Mustard

District-wise Area and Production Overview (2012–2023)

Bundelkhand: Agro-Climatic Background

Bundelkhand is characterized by:

Semi-arid climate

- Erratic and uneven rainfall
- Shallow and low water-holding capacity soils
- Heavy dependence on rainfed agriculture

Oilseeds are traditionally preferred in the region because they require comparatively less water and fit well into mixed and rainfed farming systems. However, increasing climatic stress has reduced the advantage once enjoyed by these crops.

Groundnut Trends: The district-wise analysis reveals a mixed but largely unstable trend in groundnut cultivation across Bundelkhand. Jhansi, traditionally a major groundnut-producing district, witnessed a marginal decline in area (-2.18%) during 2012–23, despite a notable increase in production (38.69%). This indicates yield improvements, possibly due to better varieties or favorable climatic years, but shrinking

District	Oilseed	Area (Hectare) (2012-2013)	Production (Tonnes) (2012-2013)	Area (Hectare) (2022-2023)	Production (Tonnes) (2022-2023)	% change in area (2012-23)	% change in production (2012-23)
Jhansi	**Groundnut**	**22,107.00**	21,687.00	21,623.00	30,078.00	-2.18935	38.69138
	Rapeseed &Mustard	7,780.00	6,372.00	16,521.00	19,528.00	112.3522	206.4658
Jalaun	**Groundnut**	9	18	40	47	344.4444	161.1111
	Rapeseed &Mustard	**9,701.00**	8,576.00	27,819.00	33,438.00	186.7643	289.9021
Lalitpur	**Groundnut**	6,675.00	7,950.00	11,203.00	8,626.00	67.83521	8.503145
	Rapeseed &Mustard	5,898.00	4,347.00	40,545.00	36,977.00	587.4364	750.6326
Hamirpur	**Groundnut**	**212**	**129**	**619**	**787**	191.9811	510.0775
	Rapeseed &Mustard	**12,965.00**	**10,929.00**	**16,211.00**	**16,260.00**	25.03664	48.77848
Mahoba	**Groundnut**	**8,368.00**	**4,853.00**	**11,348.00**	**14,503.00**	35.61185	198.8461
	Rapeseed &Mustard	**5,575.00**	**2,459.00**	**10,627.00**	**10,096.00**	90.61883	310.5734
Banda	**Groundnut**	**620**	**583**	**927**	**1,115.00**	49.51613	91.25214
	Rapeseed &Mustard	**2,672.00**	**1,584.00**	**11,334.00**	**10,201.00**	324.1766	544.0025
Chitrakoot	**Groundnut**	**42**	**26**	**1**	**1**	-97.619	-96.1538
	Rapeseed &Mustard	**2,923.00**	**1,499.00**	**2,818.00**	**3,182.00**	-3.5922	112.2748

farmer confidence in groundnut cultivation.

In contrast, districts like Jalaun, Hamirpur, Mahoba, and Banda recorded substantial increases in both area and production. However, these increases originate from very low base levels, especially in Jalaun and Hamirpur, suggesting that the absolute contribution of groundnut remains limited.

Chitrakoot presents a case of severe decline, with groundnut area and production falling by more than 95%, indicating near abandonment of the crop due to acute water stress and climatic vulnerability.

Rapeseed-Mustard Trends:

Rapeseed-mustard shows a comparatively stronger expansion across most districts of Bundelkhand. Jhansi, Jalaun, Lalitpur, Banda, and Mahoba experienced sharp increases in area (ranging from 90% to over 500%) and even higher growth in production.

Lalitpur stands out with an exceptional increase in rapeseed-mustard area (587%) and production (750%), reflecting a shift from risk-prone kharif crops towards relatively stable rabi oilseeds. However, despite this expansion, yields remain low, indicating persistent constraints related to irrigation availability and input use.

Chitrakoot again exhibits stagnation, with a slight decline in area (-3.59%) but an increase in production, suggesting yield fluctuations rather than sustained growth.

Reasons for Declining / Uneven Oilseed Performance: Factors Responsible for Declining Oilseed Production in Bundelkhand-

(i) Climatic Stress

Recurrent droughts, delayed monsoon onset, and prolonged dry spells significantly affect groundnut yields, while terminal heat stress impacts mustard during the flowering and grain-filling stages.

(ii) Rainfed Agriculture and Poor Irrigation

More than 70% of cultivated land in Bundelkhand remains rainfed. Limited irrigation facilities reduce farmers' ability to manage crop risk, particularly for water-sensitive stages of oilseed crops.

(iii) Soil Constraints

Shallow, rocky soils with low organic matter and poor water-holding capacity reduce nutrient availability and crop productivity.

(iv) Shift in Cropping Pattern

Farmers increasingly prefer wheat, pulses, or fodder crops due to assured procurement, lower market risk, and better yield stability compared to oilseeds.

(v) Low Adoption of Improved Technology

Limited access to quality seeds, fertilizers, pest management practices, and extension services has restricted productivity gains in oilseeds.

Implications for Farmers and Regional Economy:

The declining and unstable performance of oilseeds in Bundelkhand has serious implications for farmer income, nutritional security, and the regional economy. Reduced oilseed production increases dependence on imported edible oils, while farmers lose opportunities for crop diversification and income stabilization.

Given that Bundelkhand contributes significantly to agricultural employment, continued neglect of oilseed productivity may further exacerbate rural distress and migration.

Policy Recommendations

Policy Suggestions for Revitalizing Oilseed Cultivation in Bundelkhand:

- **Expansion of Micro-Irrigation**

Promotion of drip and sprinkler irrigation through targeted subsidies can enhance water-use efficiency for oilseeds.

- **Climate-Resilient Varieties**

Development and dissemination of drought- and heat-tolerant varieties of groundnut and mustard suitable for Bundelkhand conditions.

- **Strengthening Extension Services**

Farmer training on improved agronomic practices, pest management, and balanced fertilization.

- **Assured Procurement and Price Support**

Effective implementation of MSP procurement for oilseeds to reduce market risk.

- **Soil Health Improvement**

Promotion of organic matter application, green manuring, and soil testing-based nutrient management.

Government Schemes to Boost Oilseed Cultivation in Bundelkhand

The Government of Uttar Pradesh and the Government of India have launched several schemes to support farmers in increasing oilseed production in Bundelkhand. These schemes provide **seeds, training, irrigation support, price assurance, and crop insurance**, enabling farmers to adopt modern practices and reduce risk. By leveraging these programmes, farmers can expand groundnut and mustard cultivation sustainably.

1. **Free Oilseed Seed Minikits**

Benefit: Farmers receive high-yielding and climate-resilient seeds of mustard and groundnut for free. This improves crop performance, encourages sowing on more land, and reduces dependence on costly private seeds.

2. **Kisan Pathshalas & Extension Services**

Benefit: Provides hands-on training on modern farming practices, pest management, and fertilization. Helps farmers increase yields and adopt better oilseed cultivation techniques.

3. **Farm Ponds & Micro-Irrigation**

Benefit: Small ponds, drip, and sprinkler systems improve water availability in Bundelkhand's dry, rainfed fields. This ensures better growth of oilseeds and reduces crop failure during dry spells.

4. **Minimum Support Price (MSP) & Procurement Support**

Benefit: Farmers are assured a fixed price for mustard, groundnut, and other oilseeds. Reduces market risk and motivates farmers to cultivate more oilseeds instead of low-value crops.

5. **Pradhan Mantri Fasal Bima Yojana (PMFBY)**

Benefit: Provides insurance coverage for oilseed crops against drought, pests, and floods. Minimizes financial loss and encourages farmers to continue oilseed cultivation even in adverse conditions.

Conclusion: The analysis highlights that while rapeseed-mustard has shown expansion in area and production across Bundelkhand, groundnut cultivation remains highly vulnerable and uneven. Climatic uncertainty, rainfed dependence, and institutional constraints continue to limit oilseed productivity. Addressing these challenges through targeted policy interventions and climate-resilient strategies is essential for ensuring sustainable oilseed production and improving farmer livelihoods in the region.

JUST AGRICULTURE
THE FUTURE OF AGRI INNOVATION

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 26

DIVERSIFICATION IN ORNAMENTAL PRODUCTS FOR COMMERCIAL VALUE

Introduction

Flowers are an integral part of our daily lives. In a world where food grains, fruits and vegetables satiate the hunger and provide sufficient energy for life sustenance, flowers are essential for the soul, spirituality and evoke profound feelings of joy. India has a tradition saturated with flowers through various cultures and festivals. Loose flowers like marigold and desi rose are used for various religious and ceremonial functions, and also in flower arrangements like rangoli, hair adornments etc. Jasmine and tuberose (Rajnigandha) are used as a source of fragrance and for decorations in various occasions. Cut flowers (rose, carnation, gerbera, gladiolous) are used in flower arrangements, centerpieces in tables and stage decoration. Thus, it can be said that flowers are widely used on several occasions, right from a person's birth through the various activities in life and eventually, till the person passes away.

In India, both loose (stem detached) and cut flowers (stem attached) are being used and their consumption has only increased in recent times. Flowers are a highly perishable produce, and hence are used in as fresh form as possible. Depending on the flower type and their longevity, flowers eventually wither away in a stipulated period of time. A general practice is to either discard the degraded produce or to use them as compost in the field. While composting is a good option for the plants, improper disposal can lead to several other environmental hazards.

Given the amount of waste that can be generated from flowers, there is a strong need for various techniques in order to use the byproducts. Besides boosting the economy, they are additionally a supplemental source of income for people from marginalized communities.

Value addition refers to not only utilization of generated waste, but also is a method to increase economic value of the produce, either by using creative presentation/packaging methods or by employing distinct marketing strategies. They eventually fetch higher market price than the sole produce sold under traditional marketing methods. These products are ever changing and constantly evolving with the rapidly changing consumer preferences. Plant based products are quite in vogue with the new generation. With the easy access to social media, it has become comparatively easier for an individual to promote their plant based enterprises.

Dry flowers

Besides being used in the fresh form, even dried form of preserved flowers can be aesthetically utilized for making different artworks, products and interior decoration projects. Dried flowers have several advantages, viz. year round availability of raw materials and product longevity. Several products can be crafted using dry flowers, such as greeting cards, paper weights, bookmarks, collages, bouquets, soaps, potpourri, jewellery etc.

Harvesting stage affects the shelf life of dry flowers. Only those flowers have to be selected that retain their ornamental value after drying. They should be harvested at complete colour development and fully open stage.

Methods of drying:

a) Vertical drying/hanging: The flowers attached with stem, in bunches, are allowed to naturally dry on a wire (upside down) or horizontally on shelves. The drying area should be a dark, warm place with a low relative humidity (<75 per cent). It takes 3-4 weeks for complete drying of flowers. Suitable for flowers like bougainvillea, paper flower, straw flower, statice.

b) Embedded drying: Flowers are kept under a suitable dessicant (eg. sand, silica gel, borax, saw dust, alumn powder etc) in a dehydrator container. The container can either be kept in sun or in an oven for drying. Flowers suited for sun drying in 3-4 days are pansy, marigold, zinnia and chrysanthemum. Whereas under oven drying, helipterum, chrysanthemum and gerbera take about 48-50 hours at 45^{O}C to dry completely.

c) Press drying: Flowers are kept between folds of blotting paper and placed inside herbarium press or under any heavy weighted object in order to get flattened by the pressure. Flowers should be overturned on every alternate day and the paper should be changed to avoid any decay from petal exudates.

d) Water drying: It is practiced in flowers like hydrangea and celosia that are prone to getting shattered easily after drying. A small slit is made on the base of flowers and the stem is placed in a few inches of water after removal of basal leaves. The flowers are kept under a warm, dark room for 7-10 days during the drying procedure.

e) Glycerine drying: One part glycerine is mixed with two parts of warm water. The flower stems are kept at 5 cm depth in this glycerine mixture. Gradually the moisture in the leaves gets replaced with the glycerine. Certain flowers that rapidly lose moisture like hydrangea, corn flower and maple leaves are dried using this method.

Potpourri

Dried flowers that emit fragrance, along with a mixture of aromatic leaves, seeds, herbs and spices when kept inside a bowl, are termed as potpourri. In view of health, artificial room fresheners are loaded with toxic chemicals and are also a source of indoor pollutants. Hence, potpourris are completely natural and safe for indoor environment. These are great choices as gifts, and are kept inside living area, enclosed spaces like drawers, cupboards and shelves. Flowers and leaves that can be used after drying are: Jasmine, jujube, lavender, pelargonium, rose, mint, juniper and rosemary (Cook et al., 2015). Fixatives are materials used in potpourri that absorb the essential oil from natural products and gradually release them into the atmosphere. Commonly used fixatives are orris root, myrrh, sandalwood and vanilla beans. Nutmeg chippings and cinnamon peels can be also used as fixatives (Safeena and Thangam, 2023). The dried flowers alongwith fixative agents are allowed to blend inside a container for a week. Later the product can be packed in small paper sachets or perforated bags to keep them in enclosed spaces.

Flower resin jewellery

Flower-based resin jewellery is quite in trend these days. Most commonly made jewellery pieces are necklace pendants, bracelets and ear rings. Miniature, press dried flowers are preserved in the epoxy resin. The epoxy is a synthetic polymer which is highly durable. After drying, it resembles a glass and is most sought after tool for preservation of dry flowers, as the flowers are retained in their most natural form. Epoxy resin formulations consist of two parts: resin and hardener. Both of these components are mixed in equal ratio and allowed to rest for 4 minutes. It should be made sure that there are no air bubbles in the mixture. Air bubbles can be eliminated by gently blowing on the solution using a plastic straw. Further, this solution is slowly poured over the prepared mould. The mould is usually a metal ring of desired shape and size. The press dried flowers of appropriate size are placed inside the mould and can vary according to the design and availability of flowers. It takes around 8-12 hours for the resin to dry completely. Finished products have a glass-like finish. Though the products should be avoided from getting exposed to extreme sunlight, even the worn out flowers add to the rustic appeal.

Flowers that respond well and are commonly used: rose buds and petals, pansy, daisy, forget-me-not, baby’s breath, lavender, statice, chrysanthemum etc.

Skeletonized leaves

Leaf skeleton refers to the complex network of veins that are visible after all the tissues and chlorophyll content has been decomposed from the leaves. In nature, after fall (autumn season), the leaves are naturally detached and shed on the ground. While most of the leaves get completely decomposed, some leaves under complete or dappled shade undergo partial decomposition after rainfall. This leads to the development of leaf venations that are intricate and delicate. They can be found naturally in a forest, though the development is not quite uniform.

Artificial fermentation and bleaching treatments are effective in induction of skeletonized leaves. To develop uniform skeletons, the leaves can be dipped in either yeast (2 percent) or sodium hypochlorite (20 percent) solution for one hour. After the tissues have been dissolved, leaves can be kept in clear water and are gently rubbed to remove remnants of tissues between the veins. After complete drying on a flat surface, skeletons are coated with glycerin, which helps in providing the elasticity for handling the leaves. Finally the leaves can be dyed and used accordingly for creating designs in greeting cards/frames or other artwork (Mir and Jana, 2015).

Edible flowers

Certain flowers used for ornamental value can also be used for consumption. Historically, flowers have been used for enhancement of flavor and as garnishing material or as salads in several recipes. However, this should be made sure that edible flowers are free from any pesticides/insecticide residues. Most of the edible flowers are rich in vitamins (C, E and K), minerals, carbohydrates, anthocyanins, flavonoides and carotenoids. The nutritional composition tends to vary with species. Apart from direct consumption in food, herbal tea formulations are also quite popular with flowers like rose, chamomile, chrysanthemum, hibiscus and butterfly pea.

Flowers and herbs that are edible are: chive, snapdragon, begonia, borage, calendula, cornflower, marguerite daisy, carnation, fuchsia, impatiens, rose, rosemary, sage, french marigold, nasturtium, pansy (Fernandes *et al.*, 2020). Several flowers can also be used in combination with food products. For example, rice cooked with butterfly pea creeper reduces stickiness and increased cohesiveness. The antioxidant and sensory properties can be enhanced by using pumpkin flowers in chicken patties. Similarly, rose powder can be used in bakery products to enhance their nutritional qualities (Chetia *et al*., 2025)

However, it is important to note that certain flowers, owing to high alkaloid content, can lead to toxicity and should not be consumed as food products, eg. lily, delphinium, foxglove, oleander, hydrangea, anthurium, daffodil, poppy, clematis and larkspur, though some of these can be used as a medicine in small quantities.

Moss Frames

Taking inspiration from living walls, moss frames consists of dried and preserved moss of different textures. The moss is cleaned and soaked in a glycerine and water mixture, squeezed and allowed to dry on a flat surface. Glycerine helps in preservation of colour and texture. Being a dried produce, they do not require watering or sunlight. Moss frames add a touch of green element in the interior spaces without any additional efforts. These are permanent structures and should be kept away from light and moisture. Occasionally, they can be cleaned with a soft dry cloth, or can be sprayed with glycerin to retain the freshness.

Conclusion: The article focuses on various ornamental products in their fresh and dried form. There can be many other such ventures, which solely depend on an individual's creativity and awareness regarding consumer demands. Proper marketing channel, advertisements and promotions are often an essential part of the brand value. These can serve as a good option for start ups and entrepreneurship development and usually require low to moderate amount of investments. Thus, it can be concluded that ornamental products in their fresh as well as preserved forms are an essential component in contribution towards country's economy under these plant based enterprises.

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Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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GIS-ASSISTED KALANAMAK RICE CULTIVATION: A SUCCESS STORY FROM TERAI REGION GORAKHPUR

Introduction

India is one of the world's foremost rice-producing countries, accounting for a significant proportion of global rice output. It ranks first in terms of area devoted to rice cultivation and second in total production, with China occupying the corresponding alternate positions. In recent years, a substantial increase in global rice production has resulted in saturation of markets for conventional white rice. In this context, grain quality has become a decisive factor shaping consumer demand and market prices. Aromatic rice varieties, valued for their distinctive aroma, excellent cooking characteristics, and marked kernel elongation upon cooking, attract premium prices in both domestic and international markets. As a result, these specialty rices are increasingly being recognized as high-value alternatives to common rice, offering improved income prospects for rice growers.

Kalanamak is regarded as one of the most prized aromatic rice varieties cultivated in India and Nepal. The name "Kalanamak" originates from its dark-coloured husk—kala meaning black and namak meaning salt—reflecting its characteristic appearance and aroma.

Historical accounts indicate that this ancient landrace has been cultivated for over two thousand years. Traditionally, Kalanamak is grown in the Himalayan Terai region of Nepal, particularly in Kapilvastu, and in the eastern Terai belt of Uttar Pradesh, India. Renowned for its unique fragrance, superior grain quality, and cultural significance, it is often referred to as the "scented black pearl of Uttar Pradesh." Its global importance has also been recognized in international literature, including publications of the Food and Agriculture Organization of the United Nations, where it is listed among the world's specialty rice varieties.

History

Kalanamak rice has a well-established historical linkage to the Buddhist era. Archaeological excavations at Kapilvastu, the ancient capital of King Suddhodana—father of Gautama Buddha—have uncovered rice grains considered morphologically similar to Kalanamak. Kapilvastu, situated in the Terai region of present-day Nepal, is widely acknowledged for its rich historical and cultural heritage. Additional archaeological findings from Aligarhwa revealed carbonized rice grains resembling Kalanamak from a structure identified as a kitchen storage site, further substantiating the antiquity and long-standing cultivation of this rice variety.

Traditionally, Kalanamak rice was widely grown across the Terai belt of Uttar Pradesh, particularly in the districts of Siddharthnagar, Sant Kabir Nagar, Maharajganj, Basti, Gonda, and Gorakhpur. Until approximately three decades ago, Kalanamak occupied a substantial proportion of the rice-growing area in Siddharthnagar district, constituting over ten percent of the total rice acreage. However, the introduction and widespread adoption of high-yielding rice varieties, coupled with shifting production priorities, led to a sharp decline in its cultivation. By 2002, the area under Kalanamak rice had diminished to less than 0.5 percent of the total rice-growing area.

From 2017 onwards, the Agriculture Department, in coordination with the Government, implemented a series of initiatives including field demonstrations, training programmes, seminars, farmer–scientist interactions, and Kisan Melas to promote Kalanamak (Buddha) rice cultivation in the district. These sustained extension and awareness efforts led to a substantial expansion in the cultivated area, which increased from 2,715 hectares in 2018 to 18,000 hectares in 2024.

In 2024, Kalanamak rice was cultivated over approximately 18,000 hectares by around 23,000 farmers, resulting in a total production of 360,000 quintals, of which 70 percent (252,000 quintals) comprised marketable rice.

Table: Nutritional Composition of Kalanamak Rice

(Per 100 g edible portion)

Nutrient	Value
Energy	391 kcal
Protein	9.75 %
Carbohydrates	87.9 %
Dietary Fibre	1.6 g
Sugar	0 g
Total Fat	0.51 %
Iron	44.12 mg
Zinc	3.41 mg
Copper	0.37 mg
Magnesium	1.88 mg

Specialty and Features

Kalanamak rice is widely recognized as one of the world's finest specialty aromatic rice varieties and is considered comparable to premium Basmati rice in several quality attributes, except for grain length. It is classified as a non-Basmati aromatic rice with medium-slender grains and a distinct natural aroma. Due to its superior eating quality and strong heritage value, Kalanamak occupies a niche segment in both domestic and international specialty rice markets.

Currently, four improved varieties of Kalanamak rice—KN-3, Bauna Kalanamak-101, Bauna Kalanamak-102, and Kalanamak Kiran—are available for cultivation. These varieties were developed by Dr. R. C. Chaudhary and have been officially notified by the Government of India. Cooked Kalanamak rice is noted for its soft, fluffy, and non-sticky texture, mild sweetness, high digestibility, and relatively longer shelf life after cooking.

Nutrition and Health Benefits

Kalanamak rice is a nutritionally enriched aromatic rice variety and serves as a valuable source of essential micronutrients, particularly iron and zinc. Regular intake of iron- and zinc-rich foods is crucial for lowering the risk of micronutrient deficiencies, which remain widespread among vulnerable population groups. Due to its relatively higher mineral content, Kalanamak rice contributes to enhanced nutritional security and overall dietary quality.

The protein content of Kalanamak rice ranges from approximately 10 to 11 percent, which is higher than that of many widely cultivated rice varieties. This elevated protein level enhances its nutritional significance, particularly in predominantly cereal-based diets. Furthermore, Kalanamak rice exhibits a low glycemic index, reported to be between 49 and 52, making it a suitable dietary option for individuals requiring blood glucose regulation, including those with diabetes.

Traditional knowledge, supported by emerging nutritional research, suggests potential neuroprotective benefits associated with the regular consumption of aromatic and micronutrient-dense rice varieties such as Kalanamak; however, further scientific validation is necessary. In recognition of its nutritional value, the Government of India introduced the Nutri-Farm Scheme in 2013 to encourage the production and consumption of nutrient-rich crops aimed at addressing malnutrition. Under this initiative, Kalanamak rice was identified as a nutri-crop, underscoring its importance in improving population-level nutritional outcomes.

Role of GIS in the Revival of Kalanamak Rice

The revival of Kalanamak rice cultivation in the eastern Terai belt of Uttar Pradesh has been strengthened through the integration of GIS-based soil fertility mapping as a precision support tool. Under this approach, soil samples were collected from representative farmers' fields and geo-referenced to capture spatial variability in soil fertility parameters such as organic carbon, available nitrogen, phosphorus, potassium, and micronutrients.

The generated GIS soil fertility maps enabled plot-specific nutrient management, replacing traditional blanket recommendations. Based on mapped soil status, farmers adopted targeted application of farmyard manure, organic amendments, and bio-inputs, ensuring balanced nutrition tailored to local soil conditions. This precision-based intervention improved nutrient use efficiency, supported uniform crop growth, and helped maintain soil health under rainfed conditions.

By aligning traditional Kalanamak cultivation with modern spatial tools, GIS-based soil fertility mapping has played a significant role in enhancing productivity, sustaining grain quality and aroma, and reinforcing the economic viability of this heritage rice variety.

Case Study: Success Story of Ajay Kumar

(Kalanamak Rice Cultivation in Eastern Terai Belt of Uttar Pradesh)

Background of the Farmer

Ajay Kumar, a 45-year-old progressive farmer from the Gorakhpur region of Uttar Pradesh, has completed his education up to Bachelor of Arts (B.A.). Agriculture is the primary source of livelihood for his family. He owns one acre of agricultural land and additionally takes one acre on lease, cultivating a total of two acres under rice-based farming systems.

Initial Situation and Problem

Like many small and marginal farmers in the region, Ajay Kumar traditionally cultivated high-yielding non-aromatic rice varieties. Despite reasonable productivity, rising input costs, unstable market prices, and limited profit margins made rice cultivation economically unsustainable. The declining returns from conventional varieties compelled him to explore alternative crops that could provide higher income from limited landholdings. Variations in soil fertility across fields necessitated a shift towards GIS-based, plot-specific nutrient management.

Intervention and Adoption of Kalanamak Rice

Recognizing the growing market demand for specialty and aromatic rice, Ajay Kumar shifted to the cultivation of Kalanamak rice, a traditional aromatic variety well suited to the eastern Terai agro-climatic conditions. He adopted improved agronomic practices, including timely transplanting, balanced nutrient management, and careful post-harvest handling to preserve grain quality and aroma.

Kalanamak rice was cultivated on the entire two acres—one acre owned and one acre leased—under rainfed conditions with minimal external inputs, making the crop economically viable and environmentally sustainable.

To enhance yield and crop uniformity, Ajay Kumar adopted GIS-based soil fertility mapping with support from extension agencies. Soil samples were collected from different sections of his fields and geo-referenced to assess variability in soil organic carbon and available macro- and micronutrients. The fertility maps revealed nutrient imbalances across plots, particularly lower organic carbon and potassium in specific patches.

Based on these findings, Ajay Kumar followed plot-specific nutrient management, applying higher quantities of fertilizers and manures and in deficient areas, while reducing inputs in relatively fertile patches.This targeted nutrient management improved tillering, panicle formation, and grain filling, resulting in more uniform crop growth and a measurable increase in yield under rainfed conditions.

Production Performance

The adoption of GIS-guided, plot-specific nutrient management contributed to improved nutrient use efficiency and helped Ajay Kumar consistently achieve yields of **15–20 quintals** per acre without increasing input costs.

Marketing and Price Realization

Unlike conventional rice, which is usually sold at local mandis at lower prices, Ajay Kumar directly marketed his Kalanamak rice in nearby urban markets. Owing to its strong aroma, premium quality, and GI recognition, he was able to sell the produce at an average price of ₹100–150 per kg, depending on grain quality and market demand. This price was nearly double that of common Basmati and Mansuri rice, which typically fetch lower and more fluctuating prices.

Economic Impact

The cultivation of Kalanamak rice significantly improved Ajay Kumar's farm income. Even after accounting for lease rent and production costs, net returns were higher than those from conventional rice cultivation. GIS-based soil fertility mapping enabled plot-specific nutrient management, reducing unnecessary input use, improving nutrient efficiency, and supporting stable yields under rainfed conditions. Coupled with premium price realization for GI-tagged aromatic rice, Kalanamak cultivation proved economically viable for the smallholder farmer.

Outcome and Impact

The adoption of Kalanamak rice with GIS-guided precision soil management transformed Ajay Kumar's farming system from subsistence-oriented to market-oriented. Improved crop uniformity, yield stability, and grain quality enhanced overall profitability. His success has encouraged neighbouring farmers to adopt Kalanamak rice with precision management, contributing to the revival of this heritage crop and strengthening farmer livelihoods in the region.

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 28

HEALTH-PROMOTING MICROBIAL FOOD-GRADE PIGMENTS: SCOPE AND CHALLENGES

Summary

The growing demand for natural food colours has driven the shift from synthetic dyes to safe, sustainable alternatives. Microorganisms efficiently produce industrially valuable pigments-carotenoids, melanins, flavins, quinones, monascins, violacein, and indigo-through rapid, cost-effective, and genetically tractable cultivation. Extracted pigments are purified and characterised using chromatographic and spectroscopic techniques, then formulated as dispersible powders, nanoemulsions, or microencapsulated products for foods, beverages, meat, confectionery, and feeds. Commercialisation is constrained by instability, regulatory barriers, toxin risks, and limited awareness, requiring strain optimization and green technologies.

Introduction

Pigments are essential in daily life and are extensively used in agriculture, textiles, cosmetics, pharmaceuticals, and food industries. Synthetic dyes have traditionally dominated the market due to their low cost, uniform colour quality, and wide shade range. However, growing concerns highlight their adverse effects on human health and the environment (Zerin *et al.*, 2020). Many synthetic dyes are non-renewable, non-biodegradable, potentially carcinogenic, and generate toxic effluents, posing serious disposal and sustainability challenges. In contrast, natural pigments provide both colour and functional benefits such as antioxidant, anti-inflammatory, and antimicrobial activities (Ramesh *et al.*, 2019). The global food colours market is projected to grow from USD 5.7 billion in 2025 to USD 9.4 billion by 2034 at a CAGR of 5.7% (https://www.imarcgroup.com/food-colors-market), while the natural food colourants segment is expected to rise from USD 2.03 billion in 2025 to USD 2.92 billion by 2030, growing at a CAGR of 7.54% (https://www.mordorintelligence.com/industry-reports/global-natural-food-colorants-market)

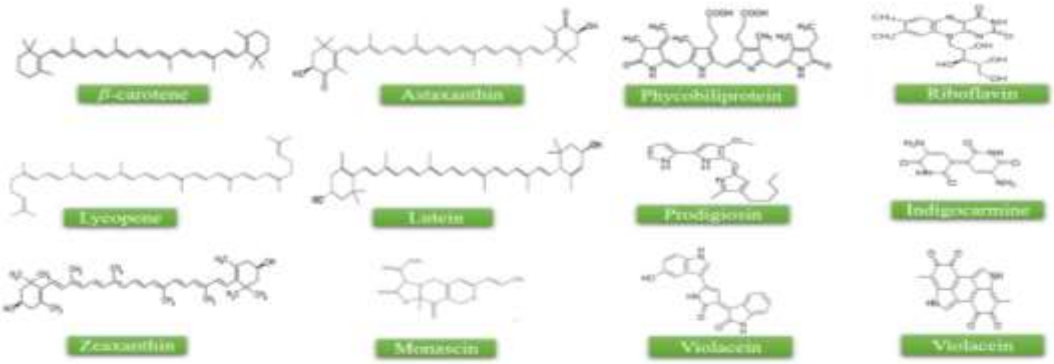

Table 1: List of Microorganisms and the Derived Pigments

Microbial Source	Major Pigment	Colour	Applications & Bioactivities
Microalgae (*Dunaliella, Haematococcus*)	Carotenoids (β-carotene, astaxanthin, lutein)	Yellow-red	Food, nutraceuticals, cosmetics; antioxidant, anti-inflammatory, anticancer activities (Saini *et al*., 2020)
Microalgae/ Cyanobacteria (*Spirulina,Nostoc*)	Phycobiliproteins	Blue-red	Food, pharmaceuticals, diagnostics; antioxidants (Sonani *et al*., 2016)
Fungi (*Monascus* spp.)	Monascins	Yellow-red	Food colourant; antioxidant, antimicrobial (Ramesh *et al*., 2019; Chen *et al*., 2019)
Bacteria	Prodigiosines, Violacein	Red, violet	Antimicrobial, anticancer, antioxidant (Sajjad *et al*., 2020)
Actinobacteria	Melanins	Black	UV protection; antioxidant; food, cosmetic and textile uses

In this context, Microbial pigments present eco-friendly, biodegradable, and bioactive alternatives to synthetic dyes, though scalable commercialization demands enhanced yield, stability, cost-efficiency, and regulatory compliance(Zerin *et al*., 2020).

Extraction, Purification, Characterisation

Microbial carotenoids are extracted using cell-disruption techniques with hydrophobic or eco-friendly solvents such as ionic liquids, deep eutectic solvents, and biosolvents. Fungal pigments are recovered using ethanol, ethyl acetate, or n-hexane aided by Soxhlet, ultrasonication, or pressurised liquid extraction. Phycobiliproteins are extracted via sonication, freeze–thaw, bead milling, or high-pressure methods. Purification involves liquid liquid extraction, chromatography, membrane systems, and aqueous two-phase systems, while characterisation employs HPLC (high-performance liquid chromatography), spectroscopy, NMR (Nuclear Magnetic Resonance), SDS-PAGE (Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoresis), and microscopy.

Table 2: Commercial Products/Formulations of Microbial Pigments

Brand/ Company	Pigment Source	Product Form
Algatech®	*Haematococcus pluvialis*	Astaxanthin powder, beadlets
Cyanotech®	*Haematococcus pluvialis*	BioAstin® oil, gel caps
Parry nutraceuticals®	*Spirulina, Chlorella*	Tablets
Nutralliance®	*Blakeslea trispora*	Beta Carotene-oil, powder, beadlets

Formulation

Pigment distribution and stability are governed by molecular structure and formulation strategy. Hydrosoluble pigments are marketed as powders or liquid concentrates, whereas liposoluble pigments are supplied as oils or dry dispersions.

Advanced approaches such as microencapsulation, cyclodextrin complexation, emulsification, and incorporation of proteins, emulsifiers, and antioxidants are employed to improve solubility, protection, and stability in food, beverage, and feed applications.

Application in the Food Industry

Beta-carotene, a red-orange carotenoid, is used as a food colourant and vitamin A source in bakery, beverages, dairy, and pharmaceuticals, supporting vision, immunity, and skin health. Astaxanthin provides red/pink hues with antioxidant and anti-ageing benefits. Other carotenoids include canthaxanthin (orange-red, feed), lutein (yellow, confectionery), lycopene (red, tomatoes, beetroot), and zeaxanthin (eye and cardiovascular health). *Monascus* pigments colour meat, dairy, and sweets, while phycobiliproteins offer blue/pink shades, with stability enhanced by preservatives.

Challenges:

Commercial deployment of microbial pigments is hindered by high production costs, stringent regulatory requirements, low tinctorial strength, physicochemical instability, matrix interactions, sensory issues, and potential mycotoxin risks, demanding robust strains and advanced stabilization strategies.

Scope for Future Improvement

Industrial application of microbial pigments is constrained by cost, safety, and stability. Advanced screening, strain improvement, optimized fermentation, and downstream processing enhance yield, while metabolic engineering, CRISPR-Cas9, and nanoformulations improve solubility, stability, and shelf life in food systems.

Conclusion:

Microbial pigments offer significant potential as natural colourants because they can be efficiently produced and modified. Progress in strain improvement, fermentation techniques, and metabolic engineering can enhance productivity and reduce costs. Future efforts should focus on identifying new pigment-producing microbes, optimising production methods, improving pigment stability and shelf life, and expanding the range of colours. Using pigments with added health benefits can increase their value and applications in the food industry.

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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 29

PRECISION WEED MANAGEMENT: SMART TECHNOLOGIES FOR SUSTAINABLE AND EFFICIENT AGRICULTURE

Introduction

Weeds continue to pose a significant threat to agricultural productivity, with estimated annual crop losses in India exceeding $11 billion. Traditional weed control methods, manual, mechanical, biological and chemical, are increasingly proving inefficient, costly and environmentally harmful. The excessive reliance on herbicides has led to widespread herbicide resistance and environmental contamination. This scenario has necessitated the development of innovative approaches like Precision Weed Management (PWM), which offers a smarter, targeted and sustainable way to combat weeds.

What is Precision Weed Management?

Precision Weed Management (PWM) is a site-specific, data-driven method that identifies and treats only weed-infested zones within a crop field. Unlike conventional uniform spraying, PWM uses advanced tools such as sensors, drones, GPS and robotics to detect weeds and apply herbicides with remarkable accuracy. The technique is grounded in the understanding that weeds are often unevenly distributed and thus, precise mapping enables targeted intervention, reducing chemical use and improving ecological balance.

The Need for a New Paradigm of PWM

There are currently 539 unique cases (species x site of action) of herbicide resistant weeds globally, with 273 species (156 dicots and 117 monocots). Weeds have evolved resistance to 21 of the 31 known herbicide sites of action and to 168 different herbicides. Herbicide resistant weeds have been reported in 102 crops in 75, traditional blanket-spraying approaches are increasingly ineffective (www.weedscience.org). Moreover, environmental regulations and public health concerns are driving the shift toward more sustainable practices. PWM provides a timely solution by:

1. Minimizing herbicide use and environmental pollution.
2. Reducing input costs for farmers.
3. Enhancing long-term crop productivity.
4. Supporting the fight against herbicide-resistant weed species.

Key Technologies in PWM

1. Weed Mapping and Detection: Using ground-based sensors, drones and satellites equipped with multispectral and hyperspectral cameras, PWM systems can accurately map weed locations.

2. Smart Sprayers and Robots: Devices such as Robovator, Hortibot and EcoRobot are capable of real-time weed detection and targeted herbicide application or mechanical removal.

3. Machine Learning and AI: Advanced algorithms differentiate between crops and weeds based on shape, spectral signature and texture.

4. Patch and Spot Spraying: Patch Spraying targets infested zones, saving up to 89% herbicides. Spot Spraying focuses on individual plants, allowing up to 99% reduction in herbicide usage.

5. Robotic Innovations: Robots like Ladybird, Bonirob and RIPPA combine sensors, AI and mechanical or chemical weeders to operate autonomously with high accuracy and low labor input.

Advantages of Precision Weed Management

1. Resource Efficiency: Herbicides are used only where necessary, reducing waste.
2. Economic Benefits: Studies report up to 60% cost savings on herbicides.
3. Environmental Protection: Limits soil, water and air contamination.
4. Improved Public Perception: Reduces health hazards and increases acceptance of chemical use.
5. Enhanced Weed Control: Higher precision leads to more effective weed suppression.
6. Research conducted across India and Europe demonstrates the practical benefits of PWM: In Rice and Greengram Fields: Drone-based spraying reduced herbicide and water usage while increasing weed control efficiency and yield (Ramesh *et al.*, 2024).
7. In Soybean and Sugar Beet Fields: Precision hoeing using automated steering led to an 87–89% weed reduction and significant yield increases (Kunz *et al.*, 2015).

Conclusion

Precision Weed Management represents a vital advancement in agricultural sustainability. By harnessing modern technology, PWM optimizes herbicide use, boosts farm profitability and protects the environment. As computing power, AI and robotics continue to evolve, the integration of PWM into mainstream farming will become not just beneficial but essential. The future of weed control lies in smart, adaptive and site-specific strategies that align with global sustainability goals.

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JUST AGRICULTURE
THE FUTURE OF AGRI INNOVATION

Just Agriculture Multidisciplinary *e- newsletter*

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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PARTICIPATORY PLANT BREEDING: FARMERS AS CO-CREATORS

Introduction

Rapid year-to-year climatic variability has increased uncertainty in agricultural production, often leading to food shortages and rising global food prices. Climate change threatens food security by altering weather patterns, intensifying extreme events and disrupting agricultural systems. Rising temperatures and changing rainfall patterns reduce crop productivity, destabilizing food supply chains. These effects are especially severe in developing regions, where vulnerability to hunger and malnutrition is high. Meeting future food demands therefore requires innovative and resilient agricultural strategies.

Enhancing genetic diversity within cropping systems is one effective approach to address these challenges. Increased diversity improves disease resistance, strengthens tolerance to climatic variability, and enhances ecosystem functions. Plant breeding plays a key role in developing high-yielding cultivars adapted to diverse and changing environments. However, conventional plant breeding often prioritizes genetic uniformity to satisfy variety registration and plant breeders' rights, which can restrict adaptive potential.

To overcome these constraints, alternative breeding strategies such as decentralized and participatory approaches have gained importance. Participatory Plant Breeding (PPB) has been widely adopted in both developed and developing countries, involving universities, CGIAR centers, research institutions and non-governmental organizations. Participatory plant breeding focuses on breeding crops directly within target environments, incorporating genotype × environment interactions to improve local adaptation Ceccarelli, 2012.

Varieties developed through PPB often exhibit greater heterogeneity, reflecting farmers' preference for stability, resilience, and suitability to local conditions. Although some studies report stability in mixed or evolving populations, long-term evidence linking stability with genetic diversity remains limited. Unlike conventional supply-driven breeding, PPB follows a demand-driven approach that begins with farmers' preferences. By combining farmers' knowledge with modern breeding tools, PPB enhances varietal relevance, biodiversity, sustainability, and farmers' capacity in selection and seed production, contributing to resilient agricultural systems (Alary, 2022).

What is Participatory Plant Breeding?

Participatory Plant Breeding (PPB) refers to a cooperative breeding approach that brings together plant breeders, farmers, marketers, processors, consumers, and policymakers. In this system, farmers actively engage with researchers and play a central role in planning, implementation, and evaluation of breeding materials. PPB is founded on the understanding that both farmers and professional breeders possess valuable and complementary knowledge, and that integrating their expertise strengthens the overall breeding process by involving multiple stakeholders at different stages.

Through PPB, farmers directly contribute to the development of crop varieties adapted to specific local environments. By combining indigenous knowledge with scientific breeding techniques, PPB facilitates the creation of resilient cultivars suitable for diverse agro-ecological conditions. This collaborative framework enhances sustainability and adaptability in agricultural systems by ensuring that developed varieties respond to real local needs.

PPB is also described using related terms such as collaborative plant breeding (CPB) and farmer participatory breeding (FPB). The term “participatory” emphasizes the active involvement of stakeholders throughout key phases of breeding and variety selection.

According to Atlin, 2001 PPB approaches are increasingly adopted and commonly include farmer-led selection, on-farm evaluation, and the use of locally adapted landraces. These programs often rely on visual selection and phenotypic mass selection for traits with simple inheritance, while also employing replicated yield trials and multi-environment testing, similar to formal breeding systems.

Strategic Goals of PPB

- **Increase production and profitability of crop production**
- **Build farmer skills to enhance farmer selection**
- **Provide benefits to a specific type of user**
- **Enhance biodiversity and increase germplasm access to local**

Kinds of participation

Kinds of Participation in Participatory Plant Breeding (PPB)

Participation in Participatory Plant Breeding (PPB) occurs along a continuum, reflecting different intensities of interaction between farmers and plant breeders. Each level of participation is defined by the extent to which farmers and breeders jointly establish breeding objectives, participate in decision-making, share responsibility for implementation, and are accountable for outcomes. These participation modes recognize that stakeholder involvement can vary depending on institutional capacity, crop type, and local context (Morris, and Bellon, 2004).

Functional Participation in PPB

Functional participation focuses on ensuring that PPB activities address the diverse needs of farming communities. Plant breeders design research strategies that consider differences in gender, socio-economic status, and resource availability. Both women and men farmers contribute valuable insights into trait preferences, labor requirements, and trade-offs among yield, quality, and resilience.

Farmers play a critical role in evaluating breeding materials under real farming conditions, allowing accurate assessment of genotype performance and trait trade-offs. On-farm trials may be managed by researchers, farmers, or jointly, ensuring that varieties are tested under authentic environmental and management conditions. Such involvement increases the relevance and effectiveness of breeding outputs and significantly enhances farmers' willingness to adopt improved varieties (Sperling *et al*. 1993).

Empowering Participation

Empowering participation emphasizes strengthening farmers' knowledge, skills, and confidence in plant breeding and seed management. Through training and hands-on involvement, farmers gain the capacity to actively engage in collaborative breeding programs and independently conduct selection and seed production. This empowerment not only improves adoption rates but also builds resilient local breeding systems and enhances the sustainability of agricultural development initiatives.

Participatory Plant Breeding (PPB) Strategies

Participatory Plant Breeding (PPB) involves shared responsibility between research institutions and farmers, with varying levels of participation. Plant breeding is based on genetic variability, environmental effects, genotype × environment interactions, and selection processes (Cleveland *et al.* 1999 and Pimbert. 2011). While making crosses is a technical task, strategic decisions such as parent selection and cross design are essential. In PPB programs, parental materials are selected from superior lines of previous cycles, with farmers and breeders jointly choosing parents. Selection occurs at multiple stages in farmers' fields, promoting continuous interaction and location-specific adaptation. Integrating morphological evaluation, drone-based tools, and PPB enhances selection efficiency and improves genetic diversity and yield stability (Farid *et al*. 2022 and Van Frank *et al.* 2020).

PPB for Self-Pollinated Crops

In self-pollinated crops, farmers grow large F_2-derived populations in their fields, and selection begins after selfing, focusing on traits with high heritability. Poor-performing populations are eliminated early, while promising bulks are selected across generations. Farmer-selected bulks often outperform later breeder selections from the same material. Selection may begin from segregating generations such as F_2 or F_3, depending on the breeding method used. Yield evaluation over multiple seasons is essential to support farmer adoption and variety release. PPB, initially aimed at smallholder farmers in developing countries, is now widely used in organic breeding programs, supported by quantitative genetic principles (Gyawali *et al*. 2007).

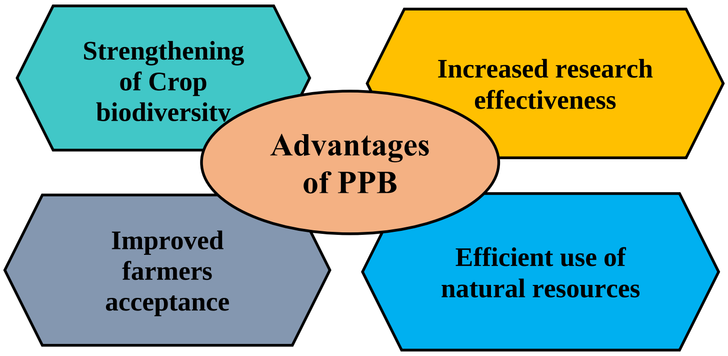
PPB Model for Population Improvement of Cross-Pollinated Crops

In cross-pollinated crops, genetic recombination is usually conducted at research stations, while selection and testing occur in farmers' fields. This approach allows selection under actual production conditions and reduces bias from field heterogeneity. Recurrent selection combined with PPB has been shown to improve both quantitative and qualitative traits in open-pollinated crops (Shelton *et al.* 2016).

PPB Model for Vegetatively Propagated Crops

In vegetatively propagated crops, once initial crosses are made, all subsequent generations are suitable for evaluation and selection directly in farmers' fields, enabling effective identification of well-adapted genotypes under local conditions.

Advantages of PPB



Future Perspectives

Advances in digital and breeding technologies are expected to significantly improve data generation, analysis, and information sharing between researchers and farmers. The future of participatory plant breeding will depend on evaluating broader impacts, particularly its role in strengthening rural innovation systems and reducing poverty. Continued emphasis on farmer involvement will enhance their participation in breeding decisions and ensure that crop varieties reflect local needs. Future breeding efforts will increasingly focus on developing climate-resilient varieties capable of withstanding emerging environmental stresses. In addition, PPB is likely to become more market-oriented, ensuring that new varieties align with consumer preferences and economic demands. However, the adoption of PPB has remained limited in marginal regions, largely due to breeding efforts historically focused on uniform agroecological and socioeconomic conditions.

Conclusion

Biodiversity loss, climate change, and food insecurity pose major global challenges that Participatory Plant Breeding (PPB) can effectively address. By promoting genetic diversity within cropping systems, PPB enhances resilience and productivity. Integration with advanced tools such as marker-assisted selection and organic farming practices further strengthens agrobiodiversity and climate adaptability. Despite constraints related to funding and regulatory frameworks, recent innovations demonstrate pathways to improve PPB effectiveness. By combining modern technologies with inclusive, farmer-centered approaches, PPB has strong potential to transform crop improvement and promote sustainable agricultural systems. Strengthening knowledge exchange and empowering farming communities will be essential for maintaining agricultural resilience under changing environmental and socioeconomic conditions.

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Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 31

2026 PATIO AND PORCH TRENDS WE LOVE

Introduction

Designing an outdoor space usually falls to the bottom of the never-ending to-do list. Between soccer practice, meal prep, and trying to keep the house standing, the patio often gets neglected

1. **Wellness Zone for Actual Relaxation**

This includes barrel saunas, cedar hot tubs, and dedicated cold plunge tubs tucked into privacy corners.Having a small (or big!) sauna or a designated stretching area on the porch removes barriers to self-care. It transforms a section of the yard into a retreat. If you have active kids or teenagers in sports, these features serve a dual purpose. A cold plunge or hot tub aids in muscle recovery after a game. It becomes a functional tool for the whole family rather than just a luxury item for adults. This trend prioritizes personal health and creates a private boundary where you can recharge.

2. Plants That Earn Their Keep

Fussy gardening is out. Nobody wants to spend their Saturday morning pruning delicate roses that might not survive a heatwave anyway. The shift is toward "plants that earn their keep." This means selecting greenery that is robust, native, and serves a specific function beyond looking nice.

You want plants that tolerate drought, repel pests, or provide food. Think of rosemary bushes that border a walkway. They smell incredible when you brush past them, require very little water, and you can clip a sprig for dinner. Native wildflowers are another strong option. They support local pollinators and generally survive without constant watering or fertilizing.

3. The Full-Service Outdoor Kitchen

Grilling burgers is a standard summer activity. However, running back inside for the ketchup, then the cheese, then a clean spatula creates chaos. The 2026 trend expands the grilling station into a full-service culinary zone. We are seeing warming drawers, outdoor-rated refrigerators, and flexible cooking surfaces like flat-top griddles.

This setup keeps the mess outside. When you cook bacon or sear fish outdoors, the smell stays out of your living room drapes. An outdoor fridge means kids can grab juice boxes without tracking mud across the kitchen floor. Warming drawers are particularly helpful for families. You can cook in batches and keep food at the right temperature until everyone is finally ready to sit down.

4. Fire Features as Gathering Anchors

Fire has a primal ability to draw people together. It stops teenagers from staring at their phones for at least a few minutes. Firepits and fireplaces remain a dominant feature because they extend the usability of your patio into the cooler months.

The current preference leans toward permanent structures or high-quality gas tables rather than disposable metal bowls. A stone fireplace acts as a focal point. It anchors the furniture arrangement and gives the eye a place to rest. Gas fire tables offer instant gratification. You flip a switch, and you have heat. There is no wood to chop and no smoke chasing you around the circle.

5. Modern Cottage Aesthetics

Strict minimalism can feel cold and uninviting, especially when plastic toys inevitably litter the ground. The "modern cottage" style offers a forgiving alternative. It blends the clean lines of modern design with the warmth and texture of a traditional English garden.

This look relies on textured furniture, like woven wicker or rope chairs, paired with softer, overflowing planting beds. It embraces imperfection. If a plant grows a little wild, it fits right in. If the cushions are a bit rumpled, it looks intentional. Materials like weathered wood and natural stone hide dirt well and age gracefully.

6. Hardscaping With Personality

Concrete slabs are functional, but they rarely inspire joy. The move toward expressive hardscaping brings character to the ground level. We are seeing large-format pavers, porcelain tiles that mimic wood or stone, and mixed material layouts.

Using different materials helps define zones without building walls. You might use large stone pavers for the dining area and pea gravel for the fire pit zone. Porcelain tile is gaining traction because it is incredibly durable, resistant to staining, and easy to spray down.

7. Understated Water Features

Big ponds and waterfalls require pumps, filters, and constant skimming. The 2026 trend scales this down to understated water features. Small fountains, bubbling urns, or micro-pools provide the soothing sound of water without the headache of maintaining a large ecosystem.

A small bubbling rock near the seating area masks traffic noise and creates a sense of seclusion. These self-contained units often recycle their own water and require very little setup. Because these features are small, they pose less of a safety risk for toddlers compared to open ponds.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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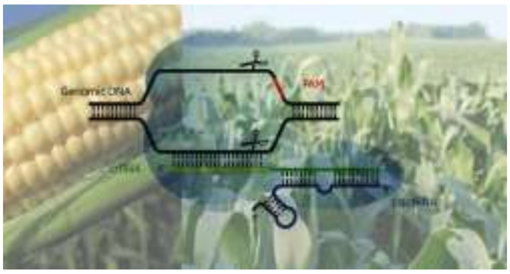
GREEN REVOLUTION TO GENE REVOLUTION: TECHNOLOGICAL ADVANCES IN AGRICULTURE

Introduction

The world is entering a new farming revolution, driven by both modern techniques and genetic science. Green Revolution 2.0 builds on past successes but adds a new approach. Instead of depending only on better irrigation and fertilizers, it uses gene editing to create stronger crops that grow well even in tough conditions. These plants produce higher yields and help fight problems like climate change, hunger, and sustainability.



Gene editing is transforming agriculture by making crops more resilient, nutritious, and high-yielding. Technologies like **CRISPR** allow scientists to modify plant DNA precisely, helping crops withstand droughts, pests, and diseases. This innovation supports **Green Revolution 2.0**, which focuses on sustainable food production using advanced genetics rather than excessive fertilizers or irrigation. Unlike traditional Genetically Modified Organisms, gene editing works by refining a plant's natural traits, making it more efficient and widely accepted.

By integrating gene editing with modern farming methods, agriculture is becoming more eco-friendly and technologically advanced. Climate-adaptive crops reduce reliance on harmful chemicals, optimize resources, and ensure global food security.

Gene Editing: Crafting Tomorrow's Crops - Precision Science for Sustainable Harvests

Agriculture plays a crucial role in food security and economic growth, feeding billions worldwide. Early advancements, like selective breeding, boosted crop yields during the **Green Revolution**, but rising food demand requires modern solutions. **Gene editing** and biotechnological tools offer precise ways to enhance plant traits, making crops more nutritious, resilient, and high-yielding.

Unlike conventional breeding, gene editing overcomes limitations like slow progress and genetic unpredictability. However, concerns over biosafety, ethics, and regulations persist.

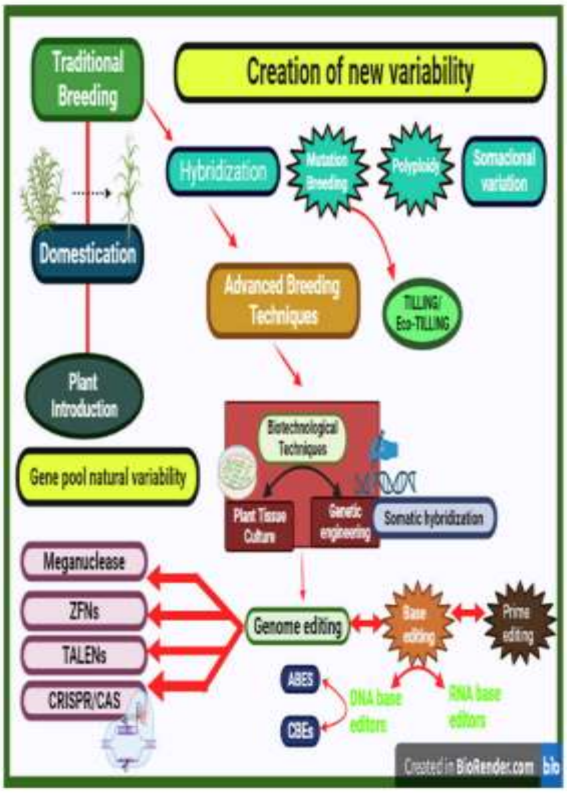
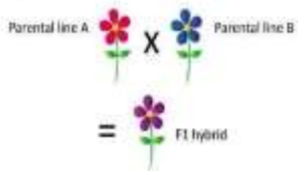


FIGURE 2
Breeding techniques across eras: tracing advances from tradition to innovation

Mutation Breeding and **Breeding Strategies for Crop Yield Improvement**

Breeding Method	Description	Key Advantages	Challenges
Mutation Breeding	Induces random mutations using radiation (X-rays, gamma-rays) or chemicals (EMS, MNU, ENU) to create new plant varieties.	Speeds up natural mutation process; generates diverse traits.	Mutations may be random; and require extensive screening.
Hybridization	Crosses two different species or varieties to create hybrids with improved traits.	Produces high-yield and resilient crops.	It requires careful selection, and there is a risk of undesired traits.
Inbreeding	Uses genetically similar parents to maintain stable characteristics over generations.	Ensures consistent desirable traits.	This can lead to reduced genetic diversity.
Self-Incompatibility	Prevents self-pollination by using genetic mechanisms or mitochondrial mutations.	It helps produce hybrid seeds efficiently.	Limited to specific plant families; complex to implement.



Recombinant DNA technology revolutionized agriculture, leading to the **Gene Revolution**, where genetically modified (GM) crops were developed for pest and herbicide resistance. Early breakthroughs used **Agrobacterium tumefaciens** for transgene transfer, creating virus-resistant and insect-resistant crops. RNA interference (RNAi) later advanced gene silencing, enabling longer shelf-life crops like **Flavr Savr tomato**. GM adoption grew rapidly, with **gene stacking** allowing multiple traits in a single plant. The USA, Brazil, and Argentina lead GM crop cultivation. With climate change threatening food security, innovations like **marker-assisted**

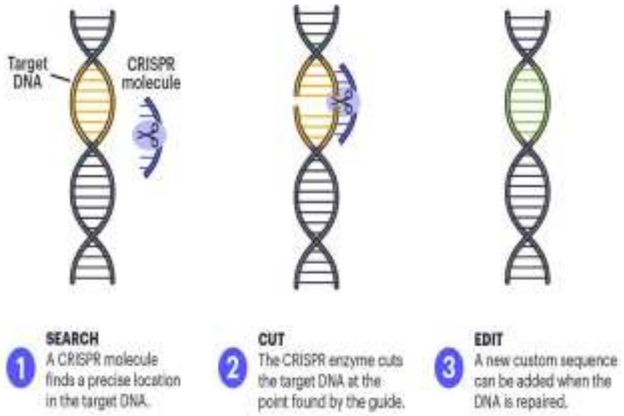
selection and **new genome editing tools** are shaping the future of high-yield, climate-resilient crops.

Advancements in Genome Editing with Sequence-Specific Nucleases (SSNs)

Genome editing has moved beyond traditional **genetically modified (GM) techniques** to more precise **sequence-specific nucleases (SSNs)**, allowing targeted modifications in plant DNA. Unlike **random gene insertions**, SSNs act as molecular scissors to create **controlled genetic changes**, improving crop resilience and productivity.

Major SSNs Used in Genome Editing

- **Meganucleases**
- **Zinc Finger Nucleases (ZFNs)**
- **Transcription Activator-Like Effector Nucleases (TALENs)**
- **CRISPR/Cas9** (most widely used due to simplicity and efficiency)



Modification Types in SSN-Based Genome Editing

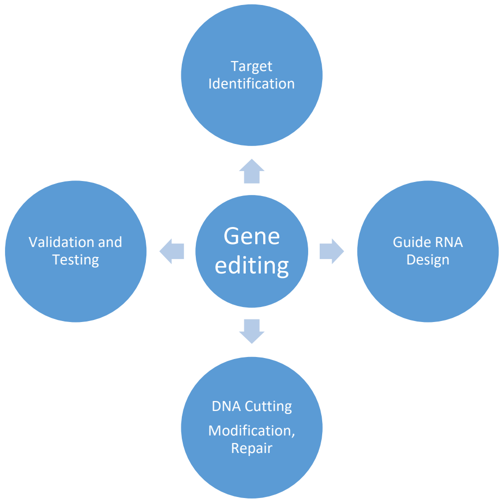
1. **Type-1 (Small Insertion/Deletion)**: Used for knockout studies, improving disease resistance in crops like rice and tomatoes.
2. **Type-2 (Substitution)**: Alters single bases for traits like longer shelf-life in tomatoes.
3. **Type-3 (Large Insertion)**: Precise gene replacements for enhanced drought tolerance and herbicide resistance.

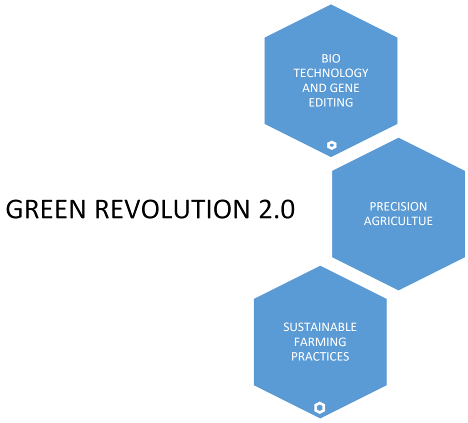
Emerging tools like **CRISPR-based editing** and **trait landing pads** facilitate precise gene stacking for multi-trait improvements.

Type of Gene Editing	Advantages	Disadvantages
CRISPR-Cas9	- High precision and efficiency. - Versatile for multiple applications. - Cost-effective.	- Risk of off-target effects. - Ethical concerns with germline editing. - Limited long-term studies.
TALEN (Transcription Activator-Like Effector Nuclease)	- Precise targeting of specific DNA sequences. - Effective for complex modifications.	- Labor-intensive design process. - Higher cost compared to CRISPR. - Limited scalability.
ZFNs (Zinc-Finger Nucleases)	- Effective for gene disruption. - Proven track record in research.	- Difficult to design. - Limited targeting capacity. - Expensive to produce.
Meganucleases	- Natural enzymes with high specificity. - Ideal for single-site modifications.	- Limited to specific DNA sites. - Less flexible compared to CRISPR. - Complex engineering required.
Base Editing	- Directly alters individual nucleotides. - Avoids double-strand breaks. - Minimal risks.	- Restricted to single base changes. - Limited applicability for large edits. - Ethical concerns.
Prime Editing	- Allows precise "search and replace" of DNA. - Reduces off-target effects. - Highly versatile.	- Complex delivery systems. - Relatively new; limited real-world data. - Higher cost and complexity.

Although challenges remain in reducing off-target effects, SSN-based genome editing is revolutionizing agriculture by enabling **climate-resilient, high-yield, and sustainable crops**.

CRISPR-based gene editing is a groundbreaking technology that allows scientists to precisely modify DNA sequences in living organisms. The term CRISPR stands for "Clustered Regularly Interspaced Short Palindromic Repeats," which are natural DNA sequences found in bacteria. These sequences, along with the Cas9 protein, form a defense mechanism against viruses, which researchers have adapted for genetic engineering. The process involves using a guide RNA to target specific DNA sequences, and the Cas9 enzyme acts like molecular scissors to cut the DNA at the desired location. This enables scientists to add, remove, or alter genetic material with remarkable accuracy.





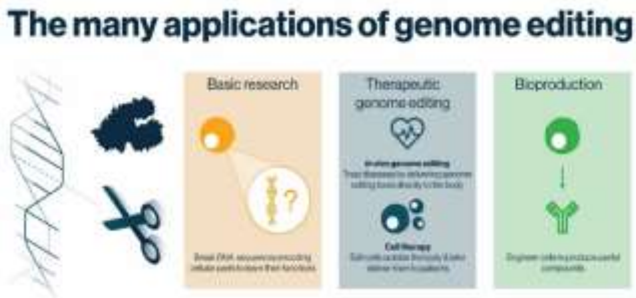


FIGURE 1
Evolution of major breeding techniques and their limitations.

The Green Revolution 2.0 tackles global challenges such as population growth, climate change, and resource constraints by utilizing advanced plant science technologies for sustainable farming. Key innovations include:

- **Precision Agriculture**: Employs advanced tools like drones, sensors, and satellite imagery to optimize resource use, reduce waste, and enhance yields sustainably.
- **Climate-Resilient Crops**: Uses breeding techniques to develop crops that can withstand heat, drought, and changing climates, ensuring stable agriculture despite weather uncertainties.
- **Regenerative Practices**: Enhances soil health and biodiversity through methods like crop rotation, cover cropping, and minimal tillage, promoting ecosystem restoration and carbon sequestration.
- **Biological Pest Control**: Utilizes eco-friendly approaches like biopesticides, beneficial insects, and microorganisms to manage pests sustainably while minimizing chemical use and resistance.
- **Gene Editing**: Enables precise genetic alterations with tools like CRISPR-Cas9, improving crop nutrition, yields, and pest resistance, while ensuring locally adapted varieties through participatory breeding.

These innovations aim to make agriculture sustainable, resilient, and environmentally friendly, balancing food production with ecosystem conservation to address global food security challenges.

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4. Google Illustrations for images

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

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ARTICLE ID: 33

DIGITAL AND PRECISION FARMING: HOW AI DATA ANALYSIS AND REAL-TIME MONITORING ARE TRANSFORMING INDIAN AGRICULTURE?

Highlights
Digital and precision farming is reshaping Indian agriculture by combining artificial intelligence (AI), data analytics, and real-time monitoring to improve productivity while reducing waste and environmental impact. These tools are moving agriculture away from intuition-based decisions toward evidence-based management by integrating information from soils, weather, crop health, and farm operations into practical recommendations. When sensors, satellites, and drones supply frequent field updates, farmers can act quickly to manage stress, pests, and resource constraints, thereby strengthening resilience in a changing climate. The central message is that digital farming is not merely a technological upgrade; it is an essential transition that can help farmers become proactive managers who produce more with fewer inputs, support sustainability goals, and meet future food demands more reliably.
Keywords: Artificial intelligence; Crop improvement; Digital agriculture; Machine learning; Sustainable agriculture

Artificial intelligence and digital technologies are transforming agriculture across the world, and the change is especially relevant in India where farmers increasingly face erratic rainfall, heat stress, rising input costs, and pressure to produce more food from limited land and water. In this context, AI-driven data analysis and real-time monitoring offer practical support by converting everyday farm observations—such as soil moisture, pest pressure, crop growth patterns, and weather trends—into actionable insights. This article explains, in accessible terms, how precision farming tools help farmers make smarter decisions, respond faster to field conditions, and increase sustainability by optimizing how water, fertilizers, and crop protection measures are used.

The new age of smart farming

Modern farming involves a level of complexity that would have been difficult to imagine even a decade ago, because crops are now managed using information streams that can include satellite observations, sensor measurements, machine-generated field maps, and predictive models. The purpose of these tools is not to replace farmers' experience but to strengthen it by improving the timing and precision of decisions such as when to irrigate, where to apply nutrients, and how to detect crop stress early. AI systems can process large volumes of data—from soil readings and weather forecasts to crop images—and translate patterns into guidance that helps protect yields, reduce costs, and minimize environmental damage, especially when the climate is unstable and markets fluctuate (Table 1).

Table 1. Major digital farming technologies and their contributions

Technology	Primary Function	Benefit to Farmers
AI & Machine Learning	Analyze field data, detect patterns, predict outcomes	Better decision-making, early problem detection
IoT Sensors	Monitor soil moisture, pH, nutrients, microclimate	Precise irrigation and nutrient management
Drones & Aerial Imaging	Capture real-time crop and field visuals	Early identification of stress, pests, and diseases
Satellite Data	Provide large-scale field conditions and weather trends	Improved planning and forecast-based management
Decision-Support Platforms	Integrate data sources into actionable recommendations	Simple, timely guidance for farms of all sizes

Real-time monitoring powers precision

Real-time monitoring makes precision farming possible because it allows farms to react quickly to changing field conditions rather than relying on periodic checks or delayed signals of stress. Internet of Things (IoT) devices placed in soil or attached to farm equipment can continuously measure moisture, temperature, pH, and nutrient status, while drones and other imaging tools can capture high-resolution views that AI models interpret to detect early disease symptoms, pest damage, or nutrient deficiencies.

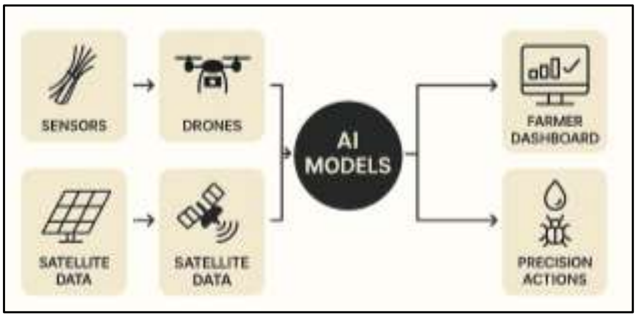

Figure 1. Workflow Diagram of a Digital Precision Farm

This near-continuous feedback helps farmers intervene at the right time and in the right place, which can reduce avoidable yield losses and limit unnecessary chemical use. It also supports better irrigation scheduling and nutrient management because inputs can be applied according to actual field needs rather than blanket assumptions across an entire farm (Figure 1).

Forecasting the unpredictable

One of the biggest advantages of digital agriculture is its ability to anticipate risks that traditional farming systems struggle to predict, particularly under increasingly unpredictable climate conditions. AI-based forecasting combines historical weather records with current sensor data and updated climate signals to warn farmers about likely heatwaves, rainfall events, or dry spells, allowing them to plan irrigation, spraying, and harvesting more strategically. Similar predictive models can also flag the risk of pest or disease outbreaks by linking local field conditions with wider patterns of pest movement and disease pressure, which helps farmers act early rather than reacting after damage has spread. Beyond the field itself, some platforms extend forecasting to market-oriented planning by helping farmers align harvesting and sales decisions with likely demand and price shifts, improving both risk management and profitability (Figure 2).

Figure 2. Predictive farming model as a forecasting cycle

Automation and robotics: a helping hand

Automation and robotics are increasingly important because many farming regions face labor shortages and rising operational costs, which make manual, repetitive tasks harder to manage at the right time. AI-enabled machines and robotic systems can support planting, weeding, targeted spraying, and harvesting while relying on computer vision and sensor guidance to work with greater precision than conventional broad-application methods. In practice, this can mean applying crop protection only where weeds or pests are detected rather than spraying an entire field, or harvesting at the optimal stage to reduce post-harvest losses. Drones and unmanned vehicles also contribute by scouting large fields quickly, generating field maps, and collecting data that feeds decision-support systems, effectively giving farmers wider visibility and faster information than would be possible through manual inspection alone.

Making data power accessible

For digital farming to succeed at scale, it must be accessible not only to large commercial farms but also to smallholders, and recent progress suggests that this transition is becoming increasingly realistic. Many precision tools are now cloud-based and mobile-friendly, allowing farmers to receive alerts, recommendations, and summaries through smartphones rather than needing expensive computer infrastructure. Several solutions are designed to integrate with existing equipment, meaning farmers can adopt precision decision support without replacing their entire production system. Platforms that combine sensor data, satellite imagery, and field records can guide farmers through the season with location-specific recommendations, while practical mobile applications can deliver timely warnings on irrigation needs or disease risk. As adoption grows, the most successful systems will be those that translate complex data into simple actions that farmers can trust and apply within their real constraints of time, labor, and investment capacity.

Sustainability gains for all

Digital and precision farming is increasingly valued not only for productivity gains but also for its potential to reduce agriculture's environmental footprint by improving the efficiency of resource use. When water, fertilizers, and pesticides are applied according to measured need, farms can reduce wastage and cut chemical runoff into water bodies, which helps protect soil health and biodiversity. Precision input management can support improved nutrient balance and healthier soils, while more accurate irrigation scheduling can conserve water in regions where groundwater depletion and rainfall variability threaten long-term sustainability. By enabling farmers to produce more with less, digital agriculture can help reconcile food security goals with environmental protection, creating benefits that extend beyond the farm gate to communities and ecosystems (Table 2).

Table 2. Benefits of AI-powered precision farming for sustainability

Sustainability Dimension	Digital Farming Contribution	Example Outcome
Water Efficiency	AI-guided irrigation scheduling	Reduced water waste and improved irrigation timing
Nutrient Management	Sensor-based fertiliser targeting	Reduced fertiliser waste and improved nutrient use efficiency
Yield Improvement	Data-driven planting and stress detection	More stable yields through timely interventions
Lower Chemical Load	Targeted pest/disease monitoring and control	Reduced pesticide runoff and non-target exposure
Soil Conservation	Monitoring soil health and organic matter	Improved soil fertility and long-term resilience

The road ahead: challenges and opportunities

Despite rapid progress, digital agriculture still faces obstacles that must be addressed for its benefits to reach all farmers and regions. Some rural areas lack reliable internet connectivity, which can limit the performance of cloud-based services, and many farmers may find the initial cost of sensors, drones, or automated systems difficult to afford without credit or supportive programs. Capacity building is equally important because tools only create value when users understand how to interpret recommendations and integrate them into daily management. Technology providers must also ensure that solutions are locally relevant, culturally acceptable, and designed around real farming practices rather than idealized conditions. With targeted training, supportive policies, and continued innovation toward affordable tools, even small farms can access valuable information through low-cost sensors and increasingly available satellite services, making data-driven farming more inclusive over time.

Conclusion: a smart farm future for all

Digital and precision farming, powered by AI and real-time data, is becoming a foundation for resilient and sustainable agriculture because it enables farmers to make faster, more accurate, and more resource-efficient decisions. By converting field variability into actionable guidance, these systems help increase productivity, reduce avoidable input costs, and lower environmental impact through more targeted irrigation and nutrient management. As climate and market conditions become more uncertain, the ability to forecast risks, detect stress early, and respond precisely will increasingly determine farm success. The future of Indian agriculture can be strengthened if these tools are deployed with attention to affordability, connectivity, and farmer training, ensuring that digital transformation supports both smallholder livelihoods and national food security while protecting natural resources for the next generation.

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 6
February, 2026

www.justagriculture.in

ARTICLE ID: 34

ROLE OF TURF GRASS MANAGEMENT IN RECREATIONAL LANDSCAPE

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Abstract

Turf grass management plays a vital role in enhancing the sustainability, functionality, and aesthetic appeal of recreational landscapes such as parks, sports fields, golf courses, and urban green spaces. Properly managed turf grass systems contribute significantly to soil stabilization, erosion control, and effective water management by improving infiltration rates and reducing surface runoff. Turf grass acts as a natural biofilter, trapping sediments, nutrients, heavy metals, and organic pollutants, thereby improving groundwater recharge and water quality. In addition to its environmental benefits, turf grass moderates urban temperatures, improves air quality by absorbing carbon dioxide and trapping dust and allergens, and reduces noise and glare in built environments. From a health and safety perspective, well-maintained turf provides a soft and resilient playing surface that minimizes injury risks while reducing pest populations and allergenic weeds. Aesthetically and socially, green and healthy turf enhances visual quality, promotes mental well-being, encourages social interaction, and increases property values, making it an integral component of recreational landscapes. Furthermore, turf grass management supports economic development by generating employment opportunities in landscaping and sports turf industries. Adoption of best management practices—including appropriate species selection, efficient irrigation, balanced fertilization, responsible pesticide use, and regular mowing—ensures the long-term sustainability and continued delivery of ecosystem services. Overall, strategic turf grass management is essential for maintaining environmentally sound, safe, and attractive recreational landscapes in rapidly urbanizing regions.

Keywords: Turf grass management; Recreational landscapes; Soil stabilization; Water quality; Ecosystem services; Urban green spaces; Environmental sustainability; Sports turf; Aesthetic value.

Introduction

Turf grass management represents an essential foundation for the success and sustainability of recreational landscapes, underpinning their environmental, functional, and social value. As the verdant base layer in parks, sports fields, golf courses, residential lawns, and urban spaces, turf grass does far more than simply beautify—it is actively engineered and cared for to deliver crucial ecosystem

Functionally, the dense shoot and root structures of turf grass anchor soil securely, offering reliable control against water and wind erosion, and acting as a natural dust and mud suppressor in built environments. The ecological advantages extend into water management: as rainfall or irrigation moves through a turf system, pollutants such as sediments, heavy metals, and organic contaminants are trapped and biologically degraded within the grass and soil matrix before they can infiltrate groundwater or run into surface waters. The improved infiltration rates provided by well-managed turf promote effective groundwater recharge and limit urban runoff, establishing turf as an important landscape feature in sustainable urban planning. From a health and safety perspective, properly managed turf grass reduces populations of harmful pests and allergens, delivers a soft and resilient surface that cushions athletic activities to reduce risk of injury, and mitigates the impact of urban heat by moderating air temperature. Its biomass supports a diverse assemblage of soil organisms, including earthworms, whose burrowing improves aeration, soil texture, and plant growth. The presence of turf grass also lowers glare, helps buffer noise, and reduces fire hazards, creating safer and more comfortable recreational settings.

Aesthetically, lush, green expanses of turf are universally recognized as symbols of cared-for, welcoming space, boosting the visual appeal of both private properties and public gathering areas.

Environmental Benefits

Proper turf grass management increases soil health by raising organic matter, fostering beneficial microorganisms, and mitigating erosion. Dense, well-maintained turf stabilizes the soil, decreases dust and runoff, and supports groundwater recharge by enhancing water infiltration rates.

Pollution Filtration and Water Quality

Turfgrass filters pollutants before groundwater recharge by acting as a dense, living filter strip that traps sediments, binds chemicals, and uses microbial activity in the root zone and thatch layer to break down contaminants. As water passes through turfgrass, the fibrous roots and thatch intercept and hold onto pesticides, heavy metals, oils, and nutrients, preventing them from quickly percolating into the soil or reaching groundwater. Microorganisms in the root zone further degrade many organic pollutants, while grass roots stabilize soil to limit erosion and runoff, ensuring cleaner water moves downward to recharge aquifers. Properly managed turf areas are thus highly effective at filtering and cleaning water before it enters groundwater supplies.

Temperature Moderation and Air Quality

Expanses of turf grass regulate temperature, providing cooling effects—often 15 to 30 degrees lower than paved or artificial surfaces. They also absorb carbon dioxide, release oxygen, and trap airborne dust and allergens, supporting a healthier urban environment.

Health and Safety

In recreational settings, turf grass offers a soft, resilient surface reducing the risk of injuries compared to hard or artificial surfaces. Managed lawns minimize populations of pests and rodents, and regular mowing reduces the production of allergy-inducing pollens.

Aesthetic and Social Value

Green, well-kept turfs enhance the beauty of public spaces, improving mental well-being, encouraging social interaction, and increasing property values. Lawns and sports fields become community hubs, supporting gatherings and activities throughout the year.

Economic and Functional Importance

Turf grass management is a significant industry, creating jobs in landscaping, sports turf management, and related sectors. Healthy turf reduces long-term maintenance costs by preventing soil degradation, surface runoff problems, and infrastructure damage due to erosion.

Best Practices in Turf Management

Efficient turf grass management includes species selection adapted to site conditions, proper irrigation, responsible fertilizer and pesticide use, and regular mowing. Employing these practices ensures sustainability and the continued delivery of ecosystem services in recreational environments.

Conclusion

In conclusion, turf grass management emerges as a central pillar in maintaining the health, functionality, and aesthetic value of recreational landscapes. Through careful selection of turf species, regular mowing, irrigation, and the thoughtful application of fertilizers and pesticides, properly managed turf areas provide lasting environmental and community benefits.

A primary advantage of expertly managed turf grass is its outstanding capacity for soil stabilization and erosion control. The intricate root systems of turf grasses bind soil, significantly minimizing erosion from wind and water—an essential attribute for parks, sports grounds, and community fields. Additionally, turf grass enhances groundwater recharge and quality by acting as a natural filter; its fibrous roots and microbial-rich thatch layer intercept, trap, and decompose pollutants before they can infiltrate groundwater supplies, thus safeguarding vital water resources. Beyond these ecosystem services, turf grass landscapes moderate urban temperatures, reduce glare, absorb sound, and improve air quality by filtering dust and atmospheric pollutants. These benefits are particularly important in urbanized settings, where recreational green spaces provide a cool refuge and contribute to healthier living environments. Health and safety are also paramount: well-maintained turf provides a soft, resilient surface that reduces injury risk for users and diminishes populations of pests and allergenic weeds through regular upkeep. Social and economic benefits further underscore the value of turf grass management—green, attractive lawns foster social cohesion, enhance mental well-being, and raise property values, while also supporting a significant industry that creates employment opportunities in landscaping and recreation sectors. Ultimately, a commitment to the best practices in turf grass management ensures that recreational landscapes remain sustainable, accessible, and enjoyable for all. As urban areas expand and the demand for quality outdoor spaces grows, the strategic stewardship of turf grass will continue to play a fundamental role in supporting environmental health, community engagement, and overall quality of life.

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