JUST AGRICULTURE
THE FUTURE OF AGRI INNOVATION

TABLE OF CONTENTS

Just Agriculture Multidisciplinary *e- newsletter*

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Piyush Kumar Yadav
M. Sc. (Ag) Horticulture, Department of Horticulture; Institute of Agriculture and Natural Sciences, Deen Dayal Upadhyaya Gorakhpur University Gorakhpur, UP.

Pallavi Kushwaha
M. Sc. (Ag) Horticulture, Department of Horticulture; Institute of Agriculture and Natural Sciences, Deen Dayal Upadhyaya Gorakhpur University Gorakhpur, UP.

Rajeev Pal
M. Sc. (Ag) Horticulture, Department of Horticulture; Institute of Agriculture and Natural Sciences, Deen Dayal Upadhyaya Gorakhpur University Gorakhpur, UP.

ARTICLE ID: 01

Hi-Tech Horticulture and Horticultural Innovations for Sustainable Production, Food Processing, and Value Addition

Abstract

Hi-tech horticulture has become a key strategy to improve productivity, quality, and profitability of horticultural crops in India, particularly for high-value crops such as cucumber, capsicum, cherry tomato, and strawberry. Modern techniques such as protected cultivation, precision farming using drones, sensors, IoT, and GIS, and advanced nursery management help farmers overcome challenges related to erratic weather, pest incidence, and soil salinity. In addition, postharvest technologies like minimal processing, value addition, biofortification, and smart packaging significantly reduce losses by 20–30%, extend shelf life, and maintain the nutritional quality of fruits, vegetables, and floricultural produce. This article reviews current innovations in high-tech horticulture, including mechanized micro-irrigation (90% water efficiency), sensor-based NDVI monitoring (10-day early deficiency detection), automation that reduces labor by 40–50%, and fertigation that improves nutrient uptake by 25–30%. These interventions are applied in crop management, physiological disorder prevention, and quality improvement. Government initiatives such as NABARD and MIDH, along with support from research organizations like ICAR and CIPHET, have promoted the adoption of these technologies, enabling more sustainable and economically viable horticulture systems across the country. The review also highlights key challenges such as high capital investment, technical skill gaps, and limited awareness among smallholder farmers, emphasizing the need for capacity building, training, and policy support. It concludes that the strategic integration of technology, scientific knowledge, and institutional support can modernize horticulture in India, reduce postharvest losses, enhance farmers' income, and promote value-added products for domestic and export markets.

Keywords: Hi-tech horticulture, Precision farming, Postharvest management, Protected cultivation, Sustainable horticulture, value addition.

1. Introduction

Horticulture is one of the fastest-growing agricultural sectors globally and makes a significant contribution to food and nutritional security (NAAS, 2018). Fruits, vegetables, flowers, and plantation crops provide essential vitamins, minerals, and antioxidants that support human health and well-being. In India, this sector contributes around one-third of agricultural gross domestic product from only about ten percent of the cultivable area while providing livelihoods to millions of rural households (Reddy, 2025). Despite its high economic value, horticulture faces several challenges, including climate-induced stress, shrinking land resources, inefficient irrigation, and heavy post-harvest losses. A temperature rise of one to two degrees Celsius can reduce yields by five to ten percent, and per-capita farmland has declined sharply from 0.4 to 0.12 hectares.

Moreover, less than half of the horticultural area is adequately irrigated, and post-harvest losses range from twenty to forty percent, amounting to approximately one lakh crore rupees annually (NABARD, 2023). Hi-tech horticulture addresses these constraints through modern technologies such as protected cultivation, precision irrigation, fertigation, soilless systems, and sensor-based monitoring, which can sharply increase productivity and resource-use efficiency (Agriallis, 2022; Maqbool et al., 2024). Equally important is effective post-harvest management, as inadequate cold chain coverage results in twenty-five to forty percent losses of fruits and vegetables (Bhattacharyya, 2017). Value-addition through processing, including products like tomato puree, dehydrated mango slices, and onion powder, extends shelf life and significantly improves farm incomes (CUTM, 2021). Integration of advanced production technologies with processing infrastructure can establish sustainable horticulture ecosystems and position India as a global leader in the sector by 2030.

2. Hi-tech Horticulture Technologies

2.1 Protected Cultivation

Protected cultivation constitutes a fundamental component of hi-tech horticulture, including greenhouse, polyhouse, and net house production systems (Singh et al., 2017; Kalmegh & Singh, 2016; Janakiram, 2022). Greenhouse, polyhouse, and net house structures enable precise control of temperature, humidity, and light intensity (Singh et al., 2017). These controlled environments shield crops from extreme weather and pests while facilitating year-round production (Maqbool et al., 2024). Tomato productivity reaches eighty to one hundred kilograms per square meter in polyhouses compared to twenty to twenty-five kilograms per square meter in open fields, representing three- to five-fold productivity gains (Sharma et al., 2024).

2.2 Hydroponics and Soilless Culture

Hydroponics facilitates plant growth without soil using nutrient-rich water solutions, enabling precise nutrient and water delivery (Patel, 2024). This technology accelerates growth and enhances productivity substantially. Strawberries produce fifty kilograms per square meter in hydroponic systems compared to five kilograms per square meter in traditional fields (eight- to ten-fold increase), while vertical nutrient film technique systems yield three hundred tons per hectare of lettuce (Gupta, 2023). Soilless cultivation conserves ninety percent water, eliminates soil-borne diseases, and proves particularly suitable for urban farming of high-value leafy greens and herbs (Kumar et al., 2025).

2.3 Precision Farming, Automation, and Micro-Irrigation

Precision farming integrates drones, sensors, IoT devices, and GIS for real-time monitoring of crop health, soil moisture, and nutrient status, supporting data-driven management decisions (Kumar et al., 2025; Anonymous, 2024). Automation enables precise irrigation and climate control, reducing labor by 40–50%. Combined with drip irrigation and fertigation, water use efficiency reaches 90%, nutrient uptake improves 25–30%, and fertilizer wastage decreases 30–40% (Patel, 2024; Sharma et al., 2024). This integrated approach optimizes growth, conserves resources, and enhances productivity per unit area.

2.4 Tissue Culture and Micropropagation

Tissue culture techniques enable rapid multiplication of disease-free, genetically uniform planting material under sterile laboratory conditions (Singh et al., 2017; Joshi, 2020). Banana plants from tissue culture yield twenty to twenty-five percent more than conventional material (ICAR, 2024). These methods prove essential for banana, potato, and ornamental crop production requiring high-quality planting stock for optimal yields and uniformity.

Table 2.1 Comparative performance of hi-tech versus traditional horticulture systems

Technology	Yield Increase	Water Conservation	Return Period
Polyhouses	Three- to five-fold	Sixty to seventy percent	Three years
Hydroponics	Eight- to ten-fold	Ninety percent	Three years
Drip and Fertigation	Twenty to thirty percent	Sixty percent	Two years
Precision Farming	Fifteen to twenty-five percent	Fifty percent	Two to three years

Source: Singh et al. (2017); Patel (2024); Sharma et al. (2024); Kumar et al. (2025)

Hi-tech systems enable off-season production, reduce chemical pesticide use by eighty to ninety percent through integrated pest management, and meet international quality standards (Maqbool et al., 2024).

2.5 Emerging Technologies

Future hi-tech horticulture development emphasizes artificial intelligence, robotics, and blockchain integration (Gupta, 2023). Artificial intelligence yield prediction models achieve ninety-five percent accuracy while robotic harvesters reduce labor costs by sixty percent (Anonymous, 2024). Blockchain traceability systems command twenty to thirty percent price premiums for certified produce (Thomas, n.d.).

3. Food Processing and Value Addition

Food processing transforms perishable horticultural produce into stable, marketable products while significantly enhancing economic value through diversified offerings including juices, pickles, sauces, dehydrated fruits, powders, and ready-to-eat preparations (Sharangi & Datta, 2015). India loses twenty-five to forty percent of three hundred fifty million tons annual horticulture production, equating to eighty-seven to one hundred forty million tons valued at one point five lakh crore rupees due to inadequate post-harvest infrastructure (Singh et al., 2025; Kumar et al., 2024).

3.1 Post-harvest Losses and Economic Impact

Vegetables suffer thirty-one percent losses while fruits lose twenty-two percent, primarily during transportation (forty percent of losses), storage (twenty-eight percent), and market handling (twenty percent) (ICAR-Central Institute of Post-Harvest Engineering and Technology, 2025). One-kilogram tomatoes yield two hundred grams puree valued at eighty rupees per kilogram plus fifty grams paste valued at one hundred fifty rupees per kilogram, generating twenty-six rupees profit versus five rupees from fresh sales - a five-fold return on investment.

3.2 Minimal Processing Technologies

High-pressure processing at six hundred megapascals retains ninety-five percent nutrients compared to sixty percent from thermal processing (Jervin Ananth et al., 2025). Cold plasma technology eliminates Escherichia coli within three minutes without chemical residues (Kaur et al., 2025). Pulsed electric field processing preserves eighty-eight percent vitamin C content while ensuring microbial safety (Gomez Saji et al., 2025). Biotechnology-based postharvest treatments and bio-preservation techniques are also emerging for maintaining quality and extending shelf life of horticultural produce (Yadav et al., 2023).

3.3 Thermal Processing Methods

Solar drying removes ninety percent water content from mangoes, extending shelf life twelve-fold while retaining seventy-five percent beta-carotene (Madhusudhan, 2025). Freeze-drying preserves ninety-five percent nutrients and maintains rehydration capacity for premium dehydrated products (Kathi et al., 2024). Ohmic heating provides uniform temperature distribution, reducing processing time by seventy percent compared to conventional methods (Patil et al., 2025).

3.4 Value-added Product Categories

Dehydration technologies produce onion powder (sixteen-fold value increase), garlic powder (twenty-fold value increase), and vegetable flakes for instant noodles. Freezing creates ready-to-eat vegetable mixes (five-fold value increase) and frozen fruit pulps for beverages. Fermentation yields pickles (three-fold value), hot sauces, and probiotic fruit beverages. Extraction technologies recover pectin from citrus waste (twenty-five-fold value), lycopene from tomato pomace (thirty-fold value), and essential oils from spent flowers (forty-fold value increase).

3.5 Emerging Processing Technologies

Emerging postharvest technologies are increasingly being adopted to improve the storability and quality of horticultural produce in India. Ozone fumigation and 1-methylcyclopropene (1-MCP) treatments have been shown to delay ripening, reduce microbial contamination, and extend shelf life without major quality deterioration. Such technologies hold strong potential for reducing postharvest losses and improving the marketability of fresh fruits and vegetables (Kurien et al., 2025; FSSAI, 2024).

3.6 Economic Case Studies

Tomato processing: One metric ton fresh tomatoes (twenty thousand rupees) yields two hundred liters puree plus fifty kilograms paste, generating one lakh fifteen thousand rupees profit (11.75-fold return vs fresh sales) (APEDA, 2025). Mango processing: One metric ton fresh mangoes (thirty thousand rupees) produce two hundred kilograms dehydrated slices (eighty lakh rupees, 26.6-fold value) (APEDA, 2025). Small-scale viability:

Twenty-five lakh rupees onion dehydration unit processes ten metric tons annually (seventy-five lakh rupees turnover, three-fold return on investment in three years). Pickle manufacturing: Ten lakh rupees startup yields forty percent margins on fifty thousand jars capacity.

3.7 Policy Support and Infrastructure Development

Pradhan Mantri Kisan Sampada Yojana provides fifty percent capital subsidy for micro food processing units while Operation Greens offers twenty-five percent transportation/storage support for tomato, onion, and potato crops (NABARD, 2023). National Mission on Food Processing allocates ten thousand crore rupees for cold chain expansion to fifty percent coverage by 2030, requiring fifty thousand crore rupees total investment by 2028. Mega Food Parks reduce logistics costs thirty percent while modified atmosphere packaging cuts losses from thirty percent to five to eight percent. Gamma irradiation facilities (ten centers) extend mango shelf life two-fold for exports to one hundred twenty countries (Krisantini et al., 2024).

4. Challenges and Opportunities

Protected cultivation (two to three crore rupees/10 acres) and hydroponics (thirty to forty lakh rupees/acre) remain unaffordable for ninety percent small farmers lacking precision training, with only ten percent cold storage coverage (Agriallis, 2022; Thomas, n.d.; NABARD, 2023).

Government counters through Mission for Integrated Development of Horticulture (fifty to ninety-five percent subsidies, one million hectares), ATMA/KVK farmer training (ten million), and National Horticulture Mission cold chain expansion (ten thousand crore rupees to fifty percent coverage) (MIDH Guidelines, 2025; NAAS, 2018; NHM, 2025; NABARD, 2023).

Future integration of AI (ninety-five percent yield prediction), robotics (sixty percent labor savings), blockchain (twenty to thirty percent price premiums), and solar greenhouses ensures scalability (Gupta, 2023; Prakash et al., 2023).

5. Conclusion

Hi-tech horticulture transforms productivity constraints into abundance. Polyhouse yields increase three- to five-fold, hydroponics eight- to ten-fold, and drip irrigation saves sixty percent water (Maqbool et al., 2024). Processing cuts twenty-five to forty percent losses to five to ten percent, creating two to five lakh crore rupees value-added market by 2030 (Singh et al., 2025).

Integrated production-processing ecosystems boost farm incomes three- to five-fold. Despite capital and skill barriers, Mission for Integrated Development of Horticulture and National Horticulture Mission (twenty thousand crore rupees) plus private investment accelerate adoption. India will emerge as a twenty-five billion dollar horticulture export leader by 2030 through hi-tech production, value addition, and digital supply chains (NAAS, 2018)

References:

1. APEDA. (2025). *Export and processing statistics for horticultural crops*. Agricultural and Processed Food Products Export Development Authority, Government of India.
2. Agriallis. (2022). *Hi-tech agriculture: A boon for Indian economy*. https://agriallis.com/wp-content/uploads/2022/06/HI-TECH-AGRICULTURE-A-BOON-FOR-INDIAN-ECONOMY.pdf
3. Anonymous. (2024). Smart hi-tech floriculture options. *Indian Horticulture*. https://epubs.icar.org.in/index.php/IndHort/article/view/160128
4. Bhattacharyya, T. (2017). *Hi-tech horticulture*. https://www.drtapasb.com/articles/Hi_tech_horticulture.pdf
5. CUTM. (2021). *Introduction to hi-tech horticulture*. https://courseware.cutm.ac.in/wp-content/uploads/2021/01/Introduction-scope-and-importance-of-Hi-Tech-Horticulture-4.pdf
6. FSSAI. (2024). *Food processing technologies and safety guidelines*. Food Safety and Standards Authority of India.
7. Gomez Saji, V., et al. (2025). Pre-treatments and packaging effects on tender jackfruit quality. *Journal of Applied Horticulture, 27*(2), 85–94.
8. Gupta, S. (2023). High-tech farming techniques in fruit crops. *International Journal of Environment and Climate Change*. https://journalijecc.com/index.php/IJECC/article/view/3440
9. ICAR. (2024). *Food processing and value addition*. https://www.agriclinics.net/rtp-material/Final%20Changed%20RTP%20module.pdf
10. ICAR–Central Institute of Post-Harvest Engineering and Technology. (2025). *Post-harvest losses assessment in fruits and vegetables in India*. ICAR-CIPHET.

11. Janakiram, T. (2022). Technological innovations in high-tech horticulture. *International Journal of Innovative Horticulture, 11*(1), 78–91.
12. Jervin Ananth, S. R., Manjula, B. S., et al. (2025). Silver nanoparticles infused biopolymer coatings extend guava shelf life. *Journal of Applied Horticulture, 27*(2), 112–120.
13. Joshi, P. (2020). Hi-tech nursery management of horticultural crops. *Planta, 1*, 52–83.
14. Kathi, S., et al. (2024). Agronomic biofortification of horticultural crops: Decade review 2012–2022. *Science of the Total Environment, 912*, 169182. https://doi.org/10.1016/j.scitotenv.2023.169182
15. Kalmegh, S., & Singh, N. (2016). Hi-tech cultivation for floriculture. *Journal of Finance and Economics, 4*(5), 151–155.
16. Kaur, S., Sharma, S., et al. (2025). Starch-lipid composite films enhance Indian jujube storability. *Journal of Applied Horticulture, 27*(2), 98–107.
17. Krisantini, et al. (2024). Gamma irradiation effects on Indonesian horticultural exports. *Journal of Food Irradiation, 15*(2), 78–89.
18. Kurien, S., et al. (2025). Ozone and one-methylcyclopropene effects on asparagus storability. *Journal of Applied Horticulture, 27*(1), 67–75.
19. Kumar, A., & Singh, R. (2024). Processing and value addition in horticulture. *Agriculture Institute*. https://agriculture.institute/basic-horticulture/processing-value-addition-horticultural-crops/
20. Kumar, A., Sharma, R., & Patel, V. (2025). Precision farming in horticulture. *Biochem Journal, 9*(2). https://www.biochemjournal.com/archives/2025/vol9issue2/PartH/9-2-90-886.pdf
21. Madhusudhan, M. (2025). Postharvest technology advancements for horticultural crops. *Journal of Applied Horticulture, 27*(1), 45–56.
22. Maqbool, A., Reddy, P. P., & Singh, R. (2024). Hi-tech horticulture: A way forward. *GreenariA, 2*(11), 77–82. https://greenaria.in/wp-content/uploads/2024/12/HI-TECH-HORTICULTURE-A-WAY-FORWARD.pdf
23. NABARD. (2023). *Hi-tech agriculture in India*. https://www.nabard.org/auth/writereaddata/careernotices/2310191602Hi-tech%20agriculture.pdf
24. NAAS. (2018). *Hi-tech horticulture policy paper*. https://naas.org.in/Policy%20Papers/Policy%2013.pdf
25. NHM. (2025). *National Horticulture Mission Annual Report 2024–25*. Department of Agriculture & Farmers Welfare, Government of India.
26. Patel, V. (2024). Precision farming potential in India. *Agronomy Journals, 7*(10). https://www.agronomyjournals.com/archives/2024/vol7issue10/PartJ/7-10-103-516.pdf
27. Patil, P., et al. (2025). Minimal processing technologies for tropical fruits. *Postharvest Biology and Technology, 210*, 112125.
28. Prakash, S., Singh, S., & Singh, B. (2023). Promotion of hi-tech horticulture. *Progressive Agriculture, 23*(1), 94–98.
29. Reddy, P. P. (2025). Hi-tech horticulture. *New Era Agriculture Magazine*. https://neweraagriculture.com/wp-content/uploads/2025/08/Article-30.pdf
30. Sharma, R., Kumar, A., & Gupta, S. (2024). Precision horticulture review. *ABR International Journal*. https://www.abrinternationaljournal.org/articles/precision-horticulture-a-modern-approach-to-smart-farming-a-review-106485.html
31. Sharangi, A. B., & Datta, S. (2015). *Value addition of horticultural crops*. Springer.
32. Singh, R., Kumar, A., & Sharma, R. (2025). On-farm processing of horticulture. *Indian Farming*. https://epubs.icar.org.in/index.php/IndFarm/article/view/163725
33. Singh, R. R., Patel, V., & Gupta, S. (2017). High-tech nursery management. *International Journal of Current Microbiology and Applied Sciences, 6*(6), 234–241. https://www.ijcmas.com/6-6-2017/R.R.%20Singh,%20et%20al.pdf
34. Thomas, A. (n.d.). Acceptance of hi-tech horticulture in Kerala. *Semantic Scholar*. https://www.semanticscholar.org/paper/A-Study-on-Acceptance-for-Hi-Tech-Horticulture-Farm-Thomas/24afa96c4b6b0b616186cb4aa24218f
35. Yadav, K., et al. (2023). Biotechnology applications in horticultural postharvest management. *Horticulture Research Journal, 12*(3), 201–215.
36. MIDH Guidelines. (2025). *Mission for Integrated Development of Horticulture Operational Guidelines 2025–26*. Government of India, Ministry of Agriculture & Farmers Welfare. https://hortnet.hortharyana.gov.in/assets/pdfs/MIDHGuidelines-OperationalGuideLines(2025-26).pdf

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

ARTICLE ID: 02

Spray Drying Technology in Agricultural Processing: Principles, Applications, and Challenges

AUTHORS' DETAILS:

Lad P. A.
Ph.D. Scholar, Department of Agricultural Processing Engineering, Dr.Annasaheb Shinde College of Agricultural Engineering and Technology, MPKV, Rahuri- 413722, Ahilyanagar, Maharashtra, India.

Dr. V. P. Kad
Associate Professor, Department of Agricultural Processing Engineering, Dr.Annasaheb Shinde College of Agricultural Engineering and Technology, MPKV, Rahuri- 413722, Ahilyanagar, Maharashtra, India.

Dr. G. N. Shelke
Assistant Professor, Department of Agricultural Processing Engineering, Dr.Annasaheb Shinde College of Agricultural Engineering and Technology, MPKV, Rahuri- 413722, Ahilyanagar, Maharashtra, India

G. M. Chavan
Ph.D. Scholar, Department of Agricultural Processing Engineering, Dr.Annasaheb Shinde College of Agricultural Engineering and Technology, MPKV, Rahuri- 413722, Ahilyanagar, Maharashtra, India.

Introduction

Spray drying turns liquid material into fine powder by spraying it into hot air, forming fine droplets that quickly evaporate into solid powder under specific temperature and pressure. Spray drying stands out as a cost-effective and commercially viable drying method. Because of its low processing costs, spray drying is one of the most widely utilized encapsulation techniques in the food and pharmaceutical industries. Spray drying plays a crucial role in revolutionizing various aspects of food processing, offering a range of applications that enhance both efficiency and product quality. Spray drying is a prominent method employed in the production of various food powders such as milk powder, coffee powder, fruit powder, coffee mate, egg yolk powder, soup, and juice powder. In the realm of dairy products, spray drying is extensively employed to convert liquid milk into powdered forms such as milk powder and whey protein powder. This not only facilitates longer shelf life but also eases transportation and storage. Spray drying can also help food maintain its appearance and nutritional value. Spray drying facilitates the retention of optimal sensory attributes and nutritional profiles, contributing significantly to the overall quality and consumer acceptability of the food items. The production of fruit powders, including those derived from berries and citrus fruits, utilizes spray drying to concentrate flavors and extend shelf life while maintaining the nutritional content.

Principles and working of Spray Drying

Spray dryer primarily consists of the following five components: spray dryer feeding system, atomization system, heating system, gas-solid separation system, and drying system. There are five primary processes in the spray drying process.

i. Concentration: Before being added to the spray dryer, feedstock is often concentrated.
ii. Atomization: This step establishes the ideal environment for evaporation, resulting in a dry product with the required properties.
iii. Droplet-air interaction: In a few of seconds, 95% plus of the water in the droplets evaporates when atomized liquid in the chamber comes into contact with heated gas.
iv. Droplet drying: There are two phases to moisture evaporation 1. During the first stage, evaporation occurs at a consistent rate and there is enough moisture in the drop to replace the liquid that evaporated at the surface. 2. When the droplet surface saturated conditions are no longer maintained by adequate moisture, a dried shell forms at the surface, signaling the start of the second stage. Then, as the shell thickens, evaporation is dependent upon moisture diffusing through it.
v. Separation: For the last step of separation, cyclones, bag filters, and electrostatic precipitators may be employed. Frequently, wet scrubbers are used to cool and cleanse the air before releasing it into the atmosphere.

Commencing with the introduction of the liquid feed into the spray drying chamber, the liquid is subjected to atomization, a pivotal stage wherein it is transformed into fine droplets. These droplets disperse within the drying chamber, presenting an enlarged surface area for efficient drying. Simultaneously, a stream of hot air or gas, known as the drying medium, is introduced into the chamber, rapidly coming into contact with the liquid droplets. The application of heat from the drying medium induces the swift evaporation of moisture within the droplets, leading to the formation of solid particles. As the moisture dissipates, the resultant dried powder descends to the chamber's bottom or is collected using a cyclone separator. Cooling mechanisms may be incorporated to prevent thermal degradation of heat-sensitive components before final collection. The entire process hinges on the meticulous control of parameters such as inlet air temperature, feed flow rate, and chamber pressure to tailor the characteristics of the end product. Spray drying stands out as an efficient and versatile method, preserving the integrity of various materials and finding applications across diverse industries.

Advantages of spray drying

Advantages of spray drying, such as enhanced product stability, efficient preservation of sensory qualities, and versatility in processing various food matrices, underscore its pivotal role in modern food processing practices. Spray drying is evident in its ability to process a wide range of food formulations, including dairy products, beverages, and fruit extracts. The technology's scalability and adaptability make it suitable for both large-scale industrial production and smaller-scale applications. The precise control over operating parameters in spray drying enables the preservation of the nutritional content and sensory attributes of food products, ensuring that the final powders retain their original flavor, color, and bioactive compounds. Transforming liquid materials into powder form decreases overall weight and volume, making storage and transportation more practical and cost-effective. The process yields powders with consistent particle size and excellent solubility, resulting in uniformity across batches and improved functionality in food and feed applications.

The fine powders produced through spray drying may exhibit issues such as caking or clumping during storage, especially in environments with high humidity. The process also demands careful control of various parameters and deviations can result in variations in particle size, morphology and consequently, the product's functionality. Scale-up challenges can arise when transitioning from laboratory to industrial-scale production, requiring meticulous optimization to maintain product consistency. In the future, spray drying is poised for advancements such as nanoencapsulation, precision atomization, integration with industry and a focus on environmentally friendly practices. These developments can revolutionize drug delivery, industrial processes, and sustainability in manufacturing. Spray drying technology is highly adaptable, offering solutions for both smallholder farmers and large-scale agro-industrial systems, supporting a wide range of production capacities.

Applications of Spray Drying

Food Industry: Spray drying is widely used in the food industry for producing powdered milk, fruit juice powder, coffee, and spices. It preserves flavor, color, and nutritional content, making it an essential method for food processing

Pharmaceutical Industry: In pharmaceuticals, spray drying is crucial for producing inhalable powders, solid dosage forms, and stable formulations. The technique enhances the solubility and bioavailability of active ingredients

Chemical Industry: Spray drying is employed in the chemical industry to produce catalysts, pigments, and specialty chemicals, ensuring uniform particle size and distribution, which is critical for performance

Limitations and Challenges

1. **Thermal Degradation**: Certain agricultural components such as vitamins, enzymes, and plant-derived bioactives are highly susceptible to heat. The elevated temperatures involved in spray drying can break down these sensitive compounds, potentially diminishing

the nutritional and functional quality of the final product.

2. **Moisture Sensitivity and Clumping**: Spray-dried powders are hygroscopic and can readily absorb moisture from humid environments. This often leads to clumping or caking, which negatively affects powder flowability, storage stability, and overall usability.

3. **Complex Process Control**: The spray drying process demands precise regulation of key variables such as inlet temperature, feed rate, and chamber conditions. Even slight deviations can result in inconsistent particle size, texture, or solubility, requiring experienced personnel and careful system calibration.

4. **High Capital Investment**: The cost of installing and maintaining spray drying systems is relatively high. This makes it less accessible for smallholder farmers or rural agro-processors with limited financial resources, thereby restricting its adoption in low-resource settings.

Conclusion: Spray drying is a vital technique in agricultural processing, transforming perishable liquid materials into stable, value-added powders. Its effectiveness in maintaining product integrity, extending shelf life, and simplifying storage and distribution has made it a cornerstone of modern agro-industrial operations. As the technology evolves, it is expected to become increasingly efficient, environmentally sustainable, and widely applicable across diverse agricultural sectors.

Just Agriculture Multidisciplinary *e- newsletter*

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Ashutosh Bharat Gawande

Young Professional, Indian Council of Agricultural Research (ICAR) – Central Institute for Cotton Research, Nagpur-441108, India

ARTICLE ID: 03

Introducing Advanced Agricultural Technologies to Transform Farming and Increase Farmers' Income in Maharashtra

Introduction

The state of Maharashtra is one of the most diversified in India in terms of agriculture sectors. The state has agro-climatic environments of high rainfall in the Konkan coastline, low rainfall in the arid Marathwada and Vidarbha regions, and this region faces various farming challenges that require new solutions. Factors such as climate change, soil degradation, labour shortages, dividing the land ownership, and systemic change are being created through stagnant farmer incomes. In the present time, Maharashtra needs to use, advanced farming technologies such as precision farming, drip irrigation, drones, smart sensor-based systems, and computer-based smart decision tools have become very important. These technologies help farmers produce more crops and help to save water, money, and resources. They also provide timely information to the farmers, which helps to reduce the risks of weather and market changes.

Current Farming Conditions in Maharashtra

Maharashtra's agriculture is very different in terms of resources, crop production, and use of technology. Some areas have irrigation and grow high-value crops like sugarcane, banana, and vegetables, but major parts of the state depend on rainwater and suffer from drought. "Shortage of water, particularly in the western and central parts of the state, still reduces crop production and affects cropping seasons. Studies show that limited awareness, high costs, and poor infrastructure have limited the use of modern technology among small farmers (Rede et al., 2024; Jadhav, 2024).

Many regions still follow traditional farming methods, leading to waste of water, increased farming costs, and damage to soil health. These challenges increase due to unstable market prices and unpredictable climate. According to Jejal and Pawar (2024), show that without the proper use of technology, agriculture cannot properly support rural livelihoods in water-shortage areas. Pilot projects prove that new technologies work better when farmers get proper training and access to money.

New Technologies Transforming Farming in Maharashtra

2. **Precision Agriculture**

Precision farming uses location data, soil information, real-time crop monitoring, and the right amount of inputs to increase efficiency and reduce waste. Instead of using the same amount of fertilizer, pesticides, and water everywhere, farmers apply only what is needed based on actual field conditions. Research indicates that precision farming helps improve both sustainable farming and farmer profits in Maharashtra (Rede et al., 2024; Khekale & Desai, 2025). Using only the required amount of nutrients reduces fertilizer loss, while controlling pests only where needed lowers chemical use and farming costs."

2. Micro-Irrigation Technologies

In Maharashtra, micro-irrigation, especially drip and sprinkler systems, is one of the most effective farming techniques. These technologies, which are providing water directly to plant roots under the Pradhan Mantri Krishi Sinchayee Yojana, are commonly used to improve water use and reduce water waste. Shroff (2024) explains that the use of drip irrigation can boost agricultural production by 73 per cent in bananas, 36 per cent in sugarcane, and 80 per cent in cotton. Depending on the crop, the amount of electricity used for irrigation decreased by 50% to 86% over this time. As a result, farmers were able to increase their profits and save money. Furthermore, by micro-irrigation (a combination of fertilizers and irrigation water), farmers are also able to directly provide nutrients to plants. This enhances the use of the plant's nutrients, conservation of the environment and reduction in loss of fertilizers. Research also indicates that farmers who do not have government subsidies should invest in drip irrigation (Shroff, 2024).

3. Drones and Aerial Analytics

Drones-based remote sensing is the new type of monitoring agriculture in Maharashtra. Drones have a camera with specific features that capture clear images of fields. Through these images, farmers are able to detect early water problems, pest problems, poor crops and even nutritional deficiencies. Chauhan et al. (2025) showed that once the drone data is integrated with the weather forecasting and crop models, farmers receive highly accurate recommendations regarding the time to irrigate, manage the pests, and harvest. Early identification of problems assists farmers in taking action on time, which minimises crop losses as well as unnecessary usage of chemicals.

4. Smart Sensor Systems for Modern Agriculture

Through the smart sensor systems technology, farmers can observe their crops from time to time. The sensors measure temperature, humidity, and moisture in the field, soil, and air. This data is sent to online systems that are constantly fed with this data; therefore, automatically inform irrigation and notify farmers from time to time that something needs to be done. Advising systems with smart sensors may be applied in irrigation and agricultural health, as it has been studied in Maharashtra and other locations (Adoption of Agri tech Innovations, 2024). With such sensors connected to the mobile applications, farmers will be able to monitor their fields anywhere and move fast in case of any complications.

5. Advanced Computer-Based Technology

In Maharashtra, there is the possibility of using smart computer technologies to minimise the risks in farming, particularly the risks linked to the changing climate, poor soil quality, and attacks by pests. They are used by analysing satellite imagery, soil test data, past year data of crops, and weather to assist farmers in determining when to plant, when to detect diseases affecting crops, and varietal selection (Khekale & Desai, 2025). Nowadays, AI-based mobile applications are used by farmers to detect pests through image and response at the time.

6. Mobile Apps and Digital Tools for Farmers

Farmers have used mobile phones as essential tools. For Weather reports, agricultural advice, market prices, crop insurance and financial services are now provided on digital platforms. The study indicates that such platforms bring improved markets, lower the cost of transaction, and improve the farmers' bargaining power (Panwar & Sahoo, 2025). These platforms also removed the use of a broker by providing direct contact between the farmers and the buyers.

e.g. The *Maha Vistar* application is a mobile app developed by the Department of Agriculture for farmers. The app provides farmers with access to various agricultural information and services through a single digital platform. It helps farmers obtain important information related to farming practices, weather conditions, and market prices. The main objective of the application is to support farmers in making timely and informed decisions by using modern digital technology, which can contribute to improved agricultural productivity and better farm management.

7. Connected Smart Tools for Farm Decision-Making

The greatest achievement in occur when different technologies, such as drones, smart sensors, AI systems, weather forecasting, and agriculture expert also support into the system (Chauhan et al., 2025). This assists farmers in receiving appropriate advice that is timely, location-specific, and useful, which significantly enhances the production of the field.

8. Effect on Farmers' Income

In Maharashtra also contribution into Micro-irrigation technology, they help into the increasing farmers' income. Increased crop production and reduced consumption of electricity directly affected farmers' net profit (Shroff, 2024). Increase the financial gains and take a clear edge through better approaches to crop management, like enhanced rice farming practices. Research indicates that better rice practices will be able to save 30-40% of costs in farming and even enhance the quality of soil (Wadghane et al.,2024).

Finally, even though some precise income data of drone and AI tools is not available yet, initial pilot projects contribute to improved crop planning, increase the use of inputs, and enhance access to markets. The digital platforms can also enable the farmers to make more money because they will reduce the marketing risks, and they will assist the farmers to receive higher prices (Panwar and Sahoo, 2025). When these technologies are facilitated with training, financial support and extension services, farmers receive the highest income.

Integrated Water Management in Sugarcane Farming

Farmers in a semi-arid region with sugarcane, drip irrigation, watering scheduling based on the weather, and soil-moisture sensors were used in combination. Sugarcane weight grew, and the number of times they irrigated diminished nearly by half in the span of two crop seasons. More reliable irrigation and reduced electricity expenses were also reported by farmers, as well as corroborated by Shroff (2024).

AI- for Monitoring Cotton Pests

Vidarbha farmers used a smart mobile app to identify pests in cotton crops. Integrating photo-based pest methods with trap data and weather data helped them significantly reduce pesticide use by approximately a third and increase the yield of the cotton crop (Khekale and Desai 2025).

Fig. 1: Modern devices.

Digital Vegetable Marketing Networks

Farmers of western Maharashtra participated in a digital market initiative where they had to provide information about the supply of crops in time to time and connected them with buyers in the city directly. The farmers were paid higher prices for their harvest and reduced the post-harvest losses with the help of digital marketing (Panwar and Sahoo 2025).

Challenges in Adopting New Farming Technology

Advanced agricultural technology has many advantages; there are several issues that provide application difficult on an all-around basis. Older farmers, and many of them do not have digital skills (Jadhav, 2024). Small farmers also cannot afford sensors, drones, and micro-irrigation systems due to their high cost, even with subsidies. The poorer internet connection in villages, unstable electricity, and insufficient qualified technicians also lower the usefulness of these technologies (Chauhan et al., 2025). Female farmers are also still struggling with access to land, credit and training.

Government Schemes and Policy Support

The Maharashtra government useful step in micro-irrigation through the Per Drop More Crop scheme. It provides subsidies and training services to farmers (Shroff, 2024). Farmers are also being assisted more annually with the help of digital soil health cards, online farm markets, digital crop insurance, and AI-based farming advice. Agricultural colleges and research stations are still experimenting with new technologies that can be used locally, and this enhances innovation in agriculture.

Future Plans for Farming

Interrelation of technologies along with team-based approach, institutional helps and equal distribution of finance by every farmer is the future of agriculture in Maharashtra. The main priorities are the enhancement of the extension services, increasing rural access to the internet, raising the level of digital literacy among farmers and promoting the use of the group-based service model. Side by side, agriculture should not be untenable so that further food production will not negatively affect the natural resources and social equality.

Conclusion

The Maharashtra agriculture is gradually transforming powerfully with the help of new technologies. The use of precision farming, micro-irrigation, AI, smart sensors, drones and digital platforms is helping farmers to produce more yields, save money, use less water, and access markets more easily. Even though the fact that issues, such as the absence of awareness, too many prices, and insufficient facilities, remain, research indicates that, under the right conditions, the technologies can significantly increase the income of farmers as well as support sustainable agriculture. This change will only be successful with the great support of the government, the constant technological improvements, and giving power to all farmers.

References

- Adoption of Agri Tech Innovations by the Sugarcane Industry in Maharashtra and Uttar Pradesh: A Comparative Analysis. (2024).
- Chauhan, M. S., Negi, R., et al. (2025). Empowering small-scale vegetable farmers with drone-based decision support systems for sustainable production. International Journal of Environment and Climate Change, 15(1), 685–697.
- Jadhav, M. (2024). Digital technology adoption among farm households in Hiware Bazaar, Maharashtra.
- Jejal, A., & Pawar, S. (2024). Sustainable agriculture in scarcity-prone regions.
- Khekale, A., & Desai, D. (2025). Transforming agriculture in Maharashtra through artificial intelligence.
- Panwar, A., & Sahoo, S. K. (2025). Socio-economic impacts of digital platforms in rural agriculture.
- Rede, G. D., Haobijam, J. W., & Seram, D. (2024). Impacts of micro-irrigation technologies in Maharashtra.
- Shroff, S. (2024). Water-saving and economic gains of the micro-irrigation adoption scheme.
- Wadghane, R., Sonawaney, V., Gotise, P., et al. (2024). Saguna Rice Technology adoption in Maharashtra.

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Anupam Soni, Indu Devi
Scientist, LPM Division, NDRI, Karnal

Sanjeet K., Verma
Scientist, LPM Division, NDRI, Karnal

ARTICLE ID: 04

Use of IoT and sensors for precise livestock monitoring and management

Introduction

Modern livestock farming is increasingly integrating Internet of Things (IoT) technologies to improve herd management efficiency and enable early detection of health issues. The **Internet of Things (IoT)** refers to interconnected digital devices capable of sensing, collecting and transmitting data through the internet for automated decision-making (Ashton, 2009). In livestock farming, IoT systems combine wearable sensors, environmental sensors, wireless networks and cloud platforms to monitor animals continuously and provide actionable information to farmers. Livestock production has become increasingly technology-intensive due to rising global demand for animal protein and the need for efficient, welfare-oriented farming practices. Traditional manual observation of animals is time-consuming, subjective and often fails to detect early signs of disease or stress. IoT-based monitoring overcomes these limitations by enabling **continuous, automated, real-time data collection** on health, behaviour, reproductive status and environmental conditions. The data collected by sensors are transmitted via communication technologies including Wi-Fi, Bluetooth, ZigBee, LoRaWAN, or cellular networks to cloud-based dashboards or mobile applications, where they are processed using data analytics or machine learning algorithm. This integration allows farmers to receive alerts on disease onset, heat stress, calving, oestrus, or abnormal behaviour much earlier than conventional methods.

Sensor Type	Primary Applications	Examples
Accelerometers / Wearables	Estrus detection, lameness detection, monitoring behavior (eating, ruminating, resting) general health alerts	Pedometers for activity neck, or leg tags tracking rumination time and activity patterns
GPS Location Trackers	Real-time location tracking, understanding grazing patterns, virtual geofencing (fenceless farming) theft prevention.	Collar-worn devices using GNSS technology to monitor herd location and send alerts if animals leave a defined area.
Intra-Ruminal Sensors	Monitoring core body temperature, rumen pH and rumen motility for early disease detection	Wireless, ingestible boluses that measure internal biomarkers
Environmental Sensors	Measuring ambient temperature, humidity, gas production (e.g., ammonia, CO2) and air quality in barns	Stationary sensors placed in barns or grazing areas to ensure optimal environmental conditions and prevent heat stress
Computer Vision (CV)	Automated weight estimation, body condition scoring, gait analysis and monitoring of group behavior.	2D (RGB), 3D and infrared thermography cameras used to analyze animal anatomy, movement and surface temperature without physical contact.
RFID Tags	Animal identification, tracking, and management, foundation for automated systems in milking or feeding	Ear tags or collars that allow for correct assignment of data to a specific animal, enabling individual care.

IoT and sensor-based livestock monitoring ultimately enhance **animal welfare**, **productivity** and **resource efficiency** by enabling precision management decisions and reducing labour requirements.

Sensor

Sensor is a device that measures a physiological or behavioral parameter of an individual animal and enables automated on-farm detection of changes that is related to a health event. Sensor word was coined byWerner von Siemens in 1928, he was also regarded as father of sensor. Passive RFID tags were first used in the mid-1970s for animal identification.

The table below summarizes the key sensor types and their primary applications in livestock monitoring.

The Data Processing

Transforming raw sensor data into actionable insights involves a structured a multi-step. The effectiveness of the entire system depends on the seamless execution of each stage:

Data Acquisition: This is the first step, where physical sensors (accelerometers, GPS, cameras, etc.) continuously collect real-time data from the animals and their environment.

Data Transferring: The collected data is transmitted to a central repository. This can use various communication protocols including Low Power Wide Area (LPWA) cellular options like LTE-M and NB-IoT for energy efficiency and good range or even satellite connectivity for remote areas with no cellular coverage.

Data Storage and Processing: The transmitted data is stored in cloud or on-premise servers. Here, Artificial Intelligence (AI), particularly Machine Learning (ML) and Deep Learning (DL) algorithms, processes the vast datasets to identify patterns, detect anomalies, and generate predictions. For example, an AI model can learn to identify the activity pattern associated with the onset of estrus or a drop in rumination time that precedes clinical illness.

Visualization of Results: The analyzed information is delivered to the end-user typically the farmer, through Decision Support Tools. This is often via user-friendly web interfaces or mobile applications that present data as clear insights, health alerts or management recommendations enabling timely intervention.

Applications of IoT and Sensor-Based Monitoring

Diseases detection - Feng *et al*. (2021) studied that continuous monitoring allows for the **early detection of diseases** like mastitis or lameness, enabling prompt treatment and reducing animal suffering. Systems can also monitor stress levels and comfort, allowing farmers to improve living conditions. Wearable temperature and movement sensors detect early signs of mastitis, respiratory disorders, metabolic diseases and heat stress. Automated alerts enable timely intervention, reducing mortality and treatment costs (Guarino *et al*., 2017). Shahab *et al*. (2024) studied that a smart sensor collar continuously measures important health signals of cattle such as body temperature, heart rate and movement. It sends this data to a cloud system and a mobile app in real time. This helps farmers quickly detect diseases like Lumpy Skin Disease (LSD) at an early stage. With timely alerts and accurate monitoring through IoT and farmers can take fast action and improve cattle health management from anywhere. Vigneswari *et al*. (2021) developed an IoT and cloud-based system to improve livestock health and farm efficiency. This system uses sensors and wearable collars to monitor animal health, track their location and manage smart feeding automatically. The data is sent to the cloud, where farmers can check it in real time. Machine learning is used to analyze the health information and detect problems early. This system supports modern precision livestock farming by making animal care faster, easier and more accurate.

Precision feeding management - Feeders with RFID capabilities provide tailored feed based on the animal's weight, stage of production and nutritional needs. Precision feeding increases feed conversion efficiency and decreases waste (Halachmi *et al.,* 2019). GPS collars help keep track on free-grazing animals, keep them from straying, maximize pasture utilization and guarantee security in vast rangelands (Umstatter, 2011). Mutiara *et al.* (2025) Smart sensors help farmers manage livestock more efficiently by providing real-time data on each animal. By analyzing this data, farmers can adjust feeding based on the specific needs of individual animals, reducing feed waste and improving productivity. Using sensor fusion and IoT technology, information from multiple sensors is collected and sent to the cloud, where it can be processed and stored for accurate monitoring and better decision-making. Automatic Feeding Systems save time by preparing and delivering feed without manual work. Farmers do not need to mix and distribute TMR or PMR themselves. These systems can be programmed to feed cows many times a day, which encourages cows to eat more often and increases dry matter intake. They also support natural feeding behaviour and help farmers monitor the health of each cow and calf more effectively (Tangorra *et al*., 2020).

Reproduction management - Unold *et al.* (2020) studied that use of cow device attached to collar of adult cow, significantly increased the activity during estrus and decreases rumination onset of mastitis with 90% accuracy. For calving, leg-mounted accelerometers plus location worked best for estrus, neck-mounted accelerometers plus localization worked best. The high rise in lying episodes prior to calving (90%) (Benaissa *et al*., 2020). Taneja *et al.* (2019) demonstrated a long-range wearable pedometer used on cows in Ireland helps monitor key behaviors such as step count, lying time and standing duration. By analyzing these activity patterns, the device can identify early signs of lameness or illness. The system was able to detect lameness up to 3 days before visible symptoms with about 87% accuracy, enabling faster treatment and better herd health management. Dineva *et al*. (2021) An IoT-based system for cattle management used Amazon cloud services to store and analyze data related to cow stress, growth, reproduction and health. Sensors like gyroscope, temperature, noise, humidity and GPS collected real-time information, which was sent to the cloud through LoRa or TCP. Thermal and video cameras were used for visual monitoring. A gateway device (AWS IoT Greengrass) used Wi-Fi to transfer all collected data to the cloud for processing and decision-making.

Precise management - Hao *et al*. (2017) developed a system that uses RFID technology to identify cows and monitor their weight to help detect breeding time. Small RFID tags were attached to the cows' ears. A hand-held RFID device and an RFID reader installed on the farm are used to read each cow's identity and weight. All information was sent through a wired network to a computer system that shows the data on a dashboard. Farmers can easily check each cow's details on the screen. Wireless sensor networks are being used to track vital signs in animals, including body temperature, respiration rate and pulse rate which are thought to be early indicators of illness. Wireless sensor networks (WSN) are used in farm optimization to measure body temperature, which is essential for detecting animal illness (Rajendran *et al*., 2023). Leliveld *et al.* (2024) they created a prototype automated system that monitors both the barn environment (like temperature, humidity, lighting and air quality) and cow behaviour at the same time. The system uses different sensors, weather station data and video cameras to collect information continuously. It processes and sends data in real time and tests on three dairy farms showed the system is stable and reliable. They suggest improving the system further by adding milking parlour data and smart algorithms so farmers can get a complete picture of cow health, welfare and milk production. The system is designed to be open, customizable and useful for research and remote automatic monitoring to support better livestock management. Jebali *et al.* (2018) developed a prototype system that uses RFID technology to monitor cattle during transportation. They studied how vibrations during transport affect the ability of RFID readers to correctly detect animals. Their goal was to improve detection accuracy and create a low cost solution for safe and reliable cattle tracking while moving them from one place to another. Benaissaa *et al*. (2023) stated that combines accelerometer sensors (to track animal movement) and UWB indoor location tracking to monitor dairy cattle behaviours like lying, feeding, drinking and eating concentrates. They used a decision tree algorithm to save energy while improving accuracy. The combined sensors helped identify cattle behaviour more correctly and allowed farmers to observe social interactions. It showed better accuracy using Bland-Altman analysis, making the system useful for smart dairy farms.

Automatic Milking System (AMSs): AMS use sensors and machine-to-machine (M2M) communication to automate farm. These systems measure and give the right amount of feed to cows based on their milk production and lactation stage. They also check milk quantity and quality either from each udder quarter or the whole cow. The sensors can provide important health information, such as somatic cell count, milk colour, milk conductivity and rumination activity. They also help detect heat (breeding time) to improve herd fertility (Filho *et al*., 2020).

Conclusion

IoT and sensor-based technologies are transforming livestock farming by allowing farmers to monitor animals continuously, accurately and automatically. These smart systems collect real-time information on animal health, behavior, feeding, reproduction and environmental conditions. By using devices such as smart collars, RFID tags, GPS trackers, accelerometers, cameras and environmental sensors, farmers can detect diseases early, improve animal welfare and reduce labor and production costs. The collected data is sent through wireless networks to cloud platforms, where artificial intelligence analyzes it and sends alerts to farmers via mobile apps. This helps farmers take quick actions during problems like mastitis, lameness, heat stress, calving or estrus. IoT also supports precision feeding, automatic milking, smart housing and better pasture utilization.

References

- Akhigbe, B. I., Munir, K., Akinade, O., Akanbi, L., & Oyedele, L. O. (2021). *IoT Technologies for Livestock Management: A Review of Present Status, Opportunities, and Future Trends.* Big Data & Cognitive Computing, 5(1), Article 10.
- Akhter, R., & Sofi, S. A. (2022). Precision agriculture using IoT data analytics and machine learning. *Journal of King Saud University – Computer and Information Sciences, 34(*8), 5602–5618.
- Arshad, J., Rehman, A. U., Othman, M. T. B., Ahmad, M., Tariq, H. B., Khalid, M. A., Moosa, M. A. R., Shafiq, M., & Hamam, H. (2022). Deployment of wireless sensor network and IoT platform to implement an intelligent animal monitoring system. Sustainability, 14(11), 6249.
- Ashton, K. (2009). That "Internet of Things" thing. *RFID Journal, 22(7),* 97-114.
- Benaissa, S., Tuyttens, F. A. M., Plets, D., Martens, L., Vandaele, L., Joseph, W., & Sonck, B. (2023). Improved cattle behaviour monitoring by combining ultra-wideband location and accelerometer data. Animal, 17, 100730.
- Benaissa, S., Tuyttens, F. A. M., Plets, D., Trogh, J., Martens, L., Vandaele, L., Joseph, W., & Sonck, B. (2020).**Improving estrus detection and calving prediction in dairy cattle using accelerometers and localization tags.** *Computers and Electronics in Agriculture*, 168, 105145.
- Chaudhry, A. A., Mumtaz, R., Zaidi, S. M. H., Tahir, M. A., & Muzammil, S. H. (2020). Internet of Things (IoT) and machine learning (ML) enabled livestock monitoring. IEEE International Conference on Smart Communities.
- Dineva, K., & Atanasova, T. (2021). Design of scalable IoT architecture based on AWS for smart livestock. Animals, 11(9), 2697.
- Eik, J. S., Yakub, F., Ilham, M. A., Aina, K., Nasrah, U., Fakharulrazi, A. N., & Harun, A. N. (2020). Control and monitoring system for livestock feeding time via smartphone. Journal of Sustainable Natural Resources.
- Feng, Y., Niu, H., Wang, F., Ivey, S. J., Wu, J. J., Qi, H., Almeida, R. A., Eda, S., & Cao, Q. (2021). SocialCattle: IoT-based mastitis detection and control through social cattle behavior sensing in smart farms. IEEE Internet of Things Journal, 9(11), 10130–10138.
- Filho, L. M. S., Lopes, M. A., Brito, S. C.,

Rossi, G., Conti, L., & Barbari, M. (2020). Robotic milking of dairy cows: A review. Semina: Ciências Agrárias, 41, 2833–2850.

- Guarino, M., Antler, A., Azarfar, A., & Halachmi, I. (2017).**The advent of sensor-based herd management systems—Trends, challenges and opportunities**. *Animal*, 11(9), 1503–1512.
- Halachmi, I., Guarino, M., Bewley, J., & Pastell, M. (2019).**Smart animal agriculture: Application of real-time sensors to improve animal well-being and productivity**. *Livestock Science, 231, 103–107.*
- Hao, S. B., Cai, S. H., Sun, R. Z., Li, J. Y., & Cheng, C. M. (2017). Design and implementation of IoT-based beef cattle breeding system. International Agricultural Engineering Journal, 26(1), 1–8.
- Jebali, C., & Kouki, A. (2018). A proposed prototype for cattle monitoring system using RFID. International Flexible Electronics Technology Conference.
- Leliveld, L. M. C., Fossati, N., Brandolese, C., Lovarelli, D., Grotto, M., Riva, E., Marinucci, A., & Provolo, G. (2024). Real-time automatic integrated monitoring of barn environment and dairy cattle behaviour: Technical implementation and evaluation on commercial farms. Computers and Electronics in Agriculture, 216, 10849.
- Ma, S., Yao, Q., Masuda, T., Higaki, S., Yoshioka, K., Arai, S., Takamatsu, S., & Itoh, T. (2021). Development of noncontact body temperature monitoring and prediction system for livestock cattle. IEEE Sensors Journal, 21(7), 8829–8838.
- Paul, P. K., Sinha, R. R., Aithal, P. S., Saavedra, R., Aremu, B., & Mewada, S. (2020). Internet of Things (IoT) and smart agriculture: With reference to applications and emerging concern. *AJES, 9(1), 37-44.*
- Pérez-Granados, C., & Schuchmann, K. L. (2024). The sound of the illegal: Applying bioacoustics for long-term monitoring of illegal cattle in protected areas. Journal of Wildlife and Biodiversity, 12(11).
- Rajendran, J. G., Alagarsamy, M., Seva, V., Dinesh, P. M., Rajangam, B., & Suriyan, K. (2023). IoT-based tracking cattle health monitoring system using wireless sensors. Bulletin of Electrical Engineering and Informatics, 12(5), 3086–3094.
- Taneja, M., Jalodia, N., Byabazaire, J., Davy, A., & Olariu, C. (2019). SmartHerd management: A microservices-based fog computing–assisted IoT platform towards data-driven smart dairy farming. Software: Practice and Experience, 49(6), 1055–1078.
- Tangorra, F. M., Agazzi, A., Perricone, V., & Costa, A. (2020). Precision feeding e automazione. In G. Ronchi, M. Savoini & T. Marinucci (Eds.), Manuale di Nutrizione dei Ruminanti da Latte (pp. 365–374). Edises Università.
- Umstatter, C. (2011).**The use of GPS systems in animal behaviour research.***Applied Animal Behaviour Science*, 135(1-2), 1–9.
- Vigneswari, T., Kalaiselvi, N., Mathumitha, K., Niveditha, A., & Sowmian, A. (2021). Smart IoT cloud-based livestock monitoring system. Turkish Journal of Computer and Mathematics Education, 12(10), 3308–3315.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Ammaiyappan A
Tamil Nadu Chief Minister's Fellow, Department of Agriculture-Farmers Welfare, Government of Tamil Nadu, Chennai – 600009, India.

Sujitha P
Tamil Nadu Chief Minister's Fellow, Department of Finance, Government of Tamil Nadu, Chennai – 600009, India.

Mary R
Tamil Nadu Chief Minister's Fellow, Department of Finance, Government of Tamil Nadu, Chennai – 600009, India.

ARTICLE ID: 05

DECADAL CHANGES IN MINIMUM SUPPORT PRICE OF MAJOR PULSES IN INDIA

ABSTRACT

Pulses play a vital role in ensuring nutritional security and promoting sustainable agriculture in India. This study examines the trend in Minimum Support Price (MSP) of major pulses, namely redgram, blackgram, greengram and bengalgram, over the period from 2013–14 to 2024–25. The analysis reveals a consistent upward trend in MSP across all crops, with greengram recording the highest increase, followed by redgram, blackgram and bengalgram. A significant rise in MSP was observed after 2017–18, indicating a shift in policy focus towards incentivizing pulse production and reducing import dependence. Despite this positive trend, the effectiveness of MSP remains constrained due to limited procurement and market inefficiencies, often preventing farmers from realizing the announced support prices. The study highlights that while MSP serves as an important policy tool, its impact can be enhanced through stronger procurement mechanisms and improved market support. Overall, a balanced approach integrating price policy with sustainable agricultural practices is essential to strengthen the pulse sector, improve farmer income and ensure long-term food and nutritional security.

INTRODUCTION

Pulses are an essential source of protein, especially for the vegetarian population in India, as they complement cereal-based diets by providing vital nutrients such as proteins, essential amino acids, vitamins and minerals (Ammaiyappan *et al*., 2023). They generally contain about 22-24 percent protein, which is much higher than that found in staple cereals like wheat and rice. Apart from their nutritional importance, pulses are also known for their health benefits, including reducing the risk of non-communicable diseases such as cardiovascular disorders and certain cancers (Ammaiyappan *et al*., 2024). These crops can be cultivated across a wide range of soil types and climatic conditions, making them highly adaptable. Pulses play a significant role in sustainable agriculture by improving soil fertility through biological nitrogen fixation and enhancing the availability of nutrients like phosphorus. Pulses are also an integral part of cropping systems such as crop rotation, intercropping and mixed cropping (Swaminathan *et al*., 2023). India is the largest producer and consumer of pulses in the world, with major crops including chickpea, pigeonpea, lentil, blackgram, greengram and others, among which chickpea dominates in terms of production share. Pulses are mainly cultivated during two seasons, namely kharif and rabi, with crops like pigeonpea, blackgram and greengram grown in kharif, while chickpea and lentil are grown in rabi. With the increasing population and rising demand for nutritious food, the requirement for pulses is expected to grow substantially in the coming years, making it necessary to enhance production through improved technologies, efficient resource use and supportive policies to ensure food and nutritional security (Adarsh et al., 2019).

Minimum Support Price (MSP) forms a key element of India's agricultural price policy, aimed at protecting farmers by ensuring a minimum guaranteed price while also maintaining affordability for consumers through mechanisms like the Public Distribution System (PDS). The concept of price support was introduced during the pre-Green Revolution period as a structured approach to encourage farmers to adopt improved agricultural technologies. Subsequently, the Agricultural Prices Commission was established in 1965, following the recommendations of the Jha Committee, to recommend support prices for various crops based on factors such as cost of cultivation. The primary objectives of this commission include ensuring fair and remunerative prices for farmers, providing reasonably priced food to consumers and promoting an efficient and sustainable cropping pattern aligned with national priorities.

Pulses: A Nutritious Food

Pulses are an essential part of the daily diet in India and are commonly consumed along with staple cereals like rice and wheat. A typical Indian meal often includes pulses, which provide a rich source of protein and help balance the carbohydrate-rich cereal-based diet. This combination improves overall nutritional quality by supplying essential amino acids required for proper growth and health.

Table 1. Nutrient Table of Pulses (per 100 g)

Pulse Crop	Energy (kcal)	Protein (g)	Carbohydrates (g)	Fiber (g)	Fat (g)
Lentils	116	9.0	20.1	7.9	0.4
Chickpeas	164	8.9	27.4	7.6	2.6
Black gram (Urad)	132	8.9	23.6	6.5	0.5
Chana dal (split)	160	8.7	27.4	8.6	2.6
Moong dal (split)	105	7.0	19.0	6.0	0.4
Whole moong	347	7.02	19.15	7.60	1.15
Tur dal	343	22.3	62.6	15.3	1.6
Peas	81	5.4	14.5	5.7	0.4

Pulses are especially important in vegetarian diets, where they act as a primary protein source and are often referred to as the "poor man's meat (Reddy *et al.*, 2023). Table 1 provide an overview of the nutritional value of the different pulses.

MINIMUM SUPPORT PRICE OF PULSES

The Minimum Support Price (MSP) of major pulses in India shown a consistent upward trend over the last decade, reflecting increasing policy support towards pulse cultivation. Among the major crops, redgram, blackgram, greengram and bengalgram exhibited steady growth in MSP, although the rate of increase varied across crops.

Redgram MSP increased from ₹4,300 per quintal in 2013–14 to ₹7,550 per quintal in 2024–25, registering an overall increase of about **75.6 percent**, showing a strong and continuous rise, particularly after 2017–18 (Figure 1). Similarly, blackgram MSP also followed a steady upward trend, rising from ₹4,300 to ₹7,400 per quintal during the same period, with an increase of around **72.1 percent** (Figure 2), indicating stable and consistent price support for this widely cultivated crop without major fluctuations. Likewise, greengram recorded the highest increase among the major pulses, with MSP rising from ₹4,500 per quintal in 2013–14 to ₹8,682 per quintal in 2024–25, reflecting a sharp increase of about **92.9 percent** (Figure 3). This significant rise, especially after 2017–18, highlights the growing importance and policy emphasis on greengram in the pulse sector. In contrast, bengalgram had comparatively lower MSP values, increasing from ₹3,100 per quintal to ₹5,650 per quintal over the study period, with an overall growth of around **82.3 percent** (Figure 4). Although the trend remained consistently upward, the increase was relatively moderate compared to greengram, indicating a comparatively lower price emphasis among major pulses.

The trend in Minimum Support Price (MSP) of pulses indicates a clear shift in policy focus over time. While MSP increases were relatively moderate in the earlier years, a more pronounced rise has been observed from 2017–18 onwards, reflecting stronger efforts to promote pulse cultivation and reduce import dependence. This pattern is evident across major pulses such as redgram, blackgram, greengram and bengalgram, all of which recorded a steady increase in MSP during the study period. The sharper increase after 2017-18 suggests a strategic intervention to improve farmer incentives and boost domestic production.

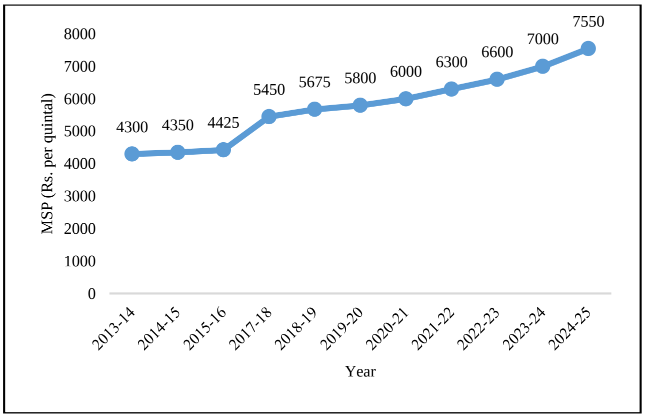


Figure 1. Minimum Support Price of Redgram

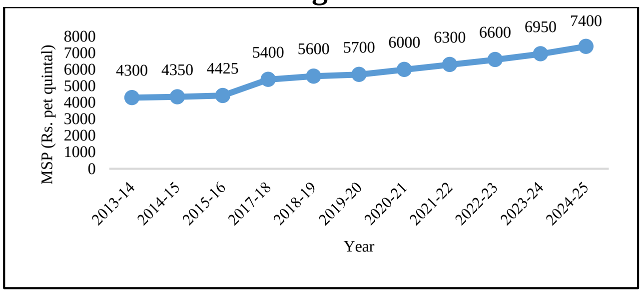


Figure 2. Minimum Support Price for Blackgram

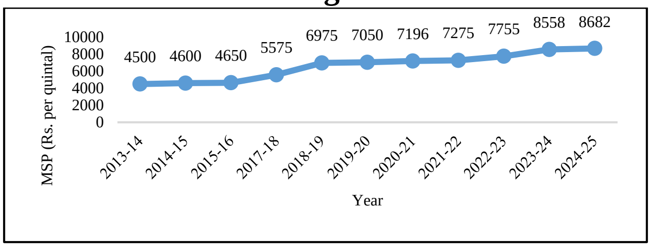


Figure 3. Minimum Support Price of Greengram

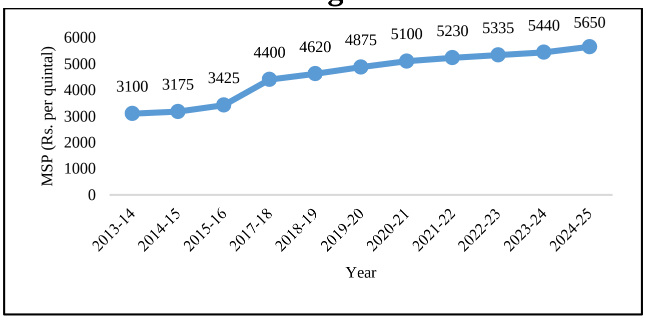


Figure 4. Minimum Support Price of Bengalgram

As a result, MSP tends to function more as a reference or indicative price rather than a guaranteed one. This highlights the need for strengthening procurement systems and market support so that the benefits of higher MSP can reach farmers and contribute to sustained growth in pulse production (Mishra *et al.*, 2023).

CONCLUSIONS

The analysis of MSP trends for major pulses highlights the growing policy emphasis on promoting pulse cultivation in India. Although MSP has increased significantly over the years, ensuring better price incentives for farmers, its full impact is limited by inadequate procurement and market support systems. Beyond price considerations, pulses play a vital role in sustainable agriculture through their environmental benefits, such as nitrogen fixation and efficient resource use, while also addressing nutritional challenges, particularly protein deficiency. Therefore, there is a need for a more comprehensive and balanced policy approach that integrates effective MSP implementation with strengthened procurement mechanisms and improved market infrastructure. Such an approach will not only enhance farmer income but also support long-term agricultural sustainability and national nutritional security.

REFERENCES

- Adarsh, S., Jacob, J., & Giffy, T. (2019). Role of Pulses in Cropping Systems: A Review. *Agricultural reviews*, *40*(3).
- Ammaiyappan, A., Infant Paul, R. A., Veeramani, A., & Kannan, P. (2024). Effect of Agronomic Manipulations on Morpho-physiological and Biochemical Responses of Rainfed Redgram [*Cajanus cajan* (L.) Millsp.]. *Legume Research: An International Journal*, *47*(8).
- Ammaiyappan, A., Paul, R., & Selvakumar, S. (2023). Nipping-Agronomic Approach for Enhancing the Pulses Production: A Review. *Agricultural Reviews*, *44*(4).
- Reddy, A. A., Bhagwat, K. D., Tiwari, V. L., Kumar, N., & Dixit, G. P. (2023). Policies and incentives for promotion of pulses production and consumption: A Review. *Journal of Food Legumes*, *36*(4), 209-228.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Dr. Renu Gangwar
Assistant Professor, College of Agriculture, Azamgarh (ANDUAT, Ayodhya)

Dr. Dhirendra Kumar Singh
Associate Dean, College of Agriculture, Kotwa, Azamgarh (ANDUAT, Ayodhya)

Dr. Anil Kumar Singh
Assistant Professor, College of Agriculture, Azamgarh (ANDUAT, Ayodhya)

ARTICLE ID: 06

Agriculture and allied micro-enterprise as livelihood opportunities for farming community

Abstract

Microenterprises are the keys to generate employment opportunities as well as income earning avenues to both landless and landholding farming community. Therefore, the poverty alleviation requires a greater understanding of the interactions of agriculture and allied enterprises and their implications for the household economy. Agriculture and allied enterprise activities enhance rural livelihood system through locally available technological backstop. In principle, poor people stand to gain from technological change generating easier access to information, higher productivity, lower inputs costs, less wastage and better environmental management. However, the pace and volatility of change can be a problem, particularly when allied activities are left behind the agriculture development or forced to take greater risks in order to keep pace with increasing vulnerability. As a result, the livelihood outcomes that allied enterprise owners practice, is likely to be increasingly determined by these activities capacity to generate and manage technological change. In the long run, an effective analysis of the factors that influence technological change in and around agriculture and allied enterprises is important for understanding the livelihood strategies and options for poor people who work in these activities.

Keywords: Agriculture, Agripreneurship, Micro-enterprise, livelihoods

Introduction

Agriculture and allied activities support livelihoods of nearly 70 per cent of India's rural population (Hiremath, 2007). In recent years, land based livelihoods of small and marginal farmers are increasingly becoming unsustainable, since their land has not been able to support the family's food requirements and fodder for their cattle. As a result, rural households are forced to look at alternative means for supplementing their livelihoods. In this context, natural resource based microenterprises have emerged as alternative livelihood opportunities in rural areas. Varying socio-economic and environmental trends including declining crop prices, swelling labour forces, migration and urbanization increased the demand for alternative employment and o farm livelihood opportunities. Due to lack of skill development, formal employment ceased to keep pace with the demand for employment. In this context, watershed development strategy facilitated small landholders, landless and women groups to benefit from small scale allied activities.

Microenterprises are informal, low costs, local business hubs for livelihood security of poor marginalized section of the society. Microenterprises are worth giving attention to for several reasons. Firstly, in some areas these make a significant contribution to household income, employment and economic production. Secondly, they have a potentially key role to play in supplying resilient and flexible services. Thirdly, compared to land based agriculture, they tend to generate relatively good income and hence provide resilience to household economic conditions.

Finally, being relatively less technology oriented, these activities support a proportionately larger section of the unskilled labour force and produce larger number of livelihoods per unit of output. So, microenterprises act as a pivotal role to generate employment opportunities as well as income earning for farming community.

Micro and Small Enterprises

Based on their nature, scale, investment limit and turnover, businesses are classified as micro, small or medium enterprises (MSMEs). These enterprises are covered under the MSME Development Act, 2006, and are broadly of two types- manufacturing or service provider. Business owners can get registered and get MSME certificates to avail of the benefits made available by the government for the growth and support of such enterprises. The Government extends support in the form of easy credit facilities, marketing support, and other steps to facilitate their growth.

Constraints in Micro and Small Enterprises

Although, microenterprises are operates locally and have low entry and exit barriers, it su ers from major constraints:

- Flow of funds (credit availability) is a major constraint for their effective operation
- Shortage of capital
- Lack of necessary skills in the chosen activity
- Competition from larger units
- Lack of marketing facilities and effective pricing for goods

Along with credit, poor people need various other services/input viz. training for skill development, information, insurance and market linkages which would minimize risk and enable them to generate income for their survival. Providing poor people with credit for microenterprise can help them work their own way out of poverty.

Strategy and Approaches

Information on microenterprise based livelihoods was drawn from a wide range of published and unpublished sources, including field research by members of GT Agro-ecosystems at ICRISAT. Although there is now rich debate and discussion on various aspects of livelihoods, there is no evidence on overall synthesis of micro enterprises, which are dependent on natural resource. This paper brings information together to create composite picture of changes in rural livelihoods and enhanced livelihood opportunities.

1. **Micro-enterprises, Markets and Technology**

Small scale entrepreneurship through watershed development plays a significant role in poor people's lives and is one of the keys to lifting people out of poverty. Some of the activities are the backbone on which the rural society survives in most arid and semiarid regions. Some projects run by government like watershed development primarily aiming sustainable management of natural resources contributing for overall agriculture development and livelihood promotion in rural areas. Initial poverty eradication e orts in India concentrated on supply of agricultural technologies, inputs and services that were often 'production' orientated. However, they were largely inappropriate to the needs of the poor and the benefits were mostly captured by the wealthy. Later, the approach changed towards 'capacity building' in sector organizations to equip people and organizations with the skills and resources to do a better job. The concept of livelihoods and livelihoods analysis emerged in the mid-nineties closely associated with poverty reduction strategies. This approach was useful to identify and prioritize the needs of the community in enhancing their livelihoods.

2. **Market Structure**

Although microenterprises operate in very informal, unregulated environments, the fortunes of most of these activities are connected by supply chains through production channels and the influence of competition, to mainstream commercial markets. These interrelationships increasingly link allied enterprise activities performance to the behavior of other actors in economic networks. However, monopoly does not arise as diverse actors are involved in the production processes. Thus, most often, microenterprise activity serves as a strong social capital, within the community, builds strong social network.

3. Role of Technological Change

In a world influenced by rapid technological developments, the capacity to cope with, generate and manage change seems like key factors in determining the livelihood strategies of poor people involved in agriculture allied enterprise. In the livelihood analysis, technology assumes greater significance as having at least four interrelated constituent's viz. technique (machines and equipment), knowledge (knowhow and skills), organization (systems, procedures, practices and support structures) and product (design, specification).

Income-Generating Micro-enterprises

1. Medicinal and Aromatic Plant Extracts

Medicinal and aromatic plants possess the ability to grow in poor soils and under low rainfall and moisture conditions, thereby assisting in the natural regeneration of these crops. These crops improve specialized skills; encourage contacts with niche markets; adds to crop diversification; and provides employment opportunities (Rangarao, 2009). Value addition to medicinal and aromatic plants product is one of the objectives of crop diversification. Processing of aromatic plants by extraction of oil is value addition to lemongrass, palmarosa, vetiver, and Eucalyptus citriodora (Reddy *et al*., 2008).

2. Apiculture

The harvesting of honey from the forest has been in practice since long and huge pro ts from this enterprise promoted rearing bees in the farms. In the recent past rural communities while diversifying their agricultural practices, have adopted this practice gradually. Production of honey from farmlands can be a secondary activity for farmers as it requires less time as compared with other activities and can be carried out by women in a house. On an estimate, about 80 per cent of honey is used directly in medicines and 10 per cent is used in Ayurvedic and pharmaceutical production (GOI, 2006). Studies found that apiculture is an excellent, esthetic livelihood generating endangered hobby. It has a potential market with environmental responsibility and worldwide medicinal and nutritional recognition.

3. Upgrading and Rearing Livestock

Small ruminants like, sheep or goats are the best source of regular cash income throughout the year for rural poor without much investment. They form a major component in a tree crop livestock diversification/integration paradigm. As integrated crop dairy farming system is a viable and pro table proposition to the farmers, upgrading livestock is essential.

4. Vermiculture

Vermiculture became a prominent microenterprise for rural landless and women groups, as it requires low investment. Vermiculture is environment friendly as it converts disposal of organic wastes generated in farms as well as in household front as productive plant nutrient. These residues contain valuable plant nutrient and can be effectively used for increasing the agricultural productivity. Earthworms convert the residues into valuable source of plant nutrients by feeding on the organic material and excreting out valuable organic manure. Earthworms are one of the major soil macro invertebrates. The role of earthworms in the soil is to improve soil fertility and soil health. Vermicompost increases water holding capacity of the soil, promotes crop growth, helps produce more, and improves food and fodder quality

5. Poultry based Activities

Agro wastes (e.g, from maize cultivation) can be diverted for poultry feed along with other supplemental food. Rearing of improved breed like broilers can increase the returns and improve the livelihood options.

6. Horticulture and Forestry based Activities

Teak planting, pomegranate cultivation and custard apple cultivation along the bunds and marginal lands will provide pro t to the farmers.

Incentives for Micro & Small Enterprises (MSEs)

Many incentives are provided to Micro and Small units to support the business and promote Small Employment Ventures. Notable among these are:

- **i.** Prime Minister's Employment Generation Program to facilitate the growth of Self-Employment.
- **ii.** Price and Purchase preference for products manufactured by MSEs in Govt. Purchase Program.
- **iii.** Credit Policies for Priority Lending to

MSEs.

- **iv.** Interest in the Delayed Payment Act to tackle the problem of Settlement of MSME dues from large-scale units.
- **v.** Integrated Infrastructure Development (IID) Centre to provide basic infrastructure facilities.
- **vi.** National Equity Fund Scheme and Technology Development.
- **vii.** Modernization Fund Schemes.
- **viii.** Market Development Assistance for MSE Exporters.
- **ix.** Credit Linked Capital Subsidy Scheme for Technology up gradation.
- **x.** Reimbursement of ISO 9000, ISO-14000 & HACCP.
- **xi.** MSME Cluster Development Program.
- **xii.** National Manufacturing Competitiveness Program Schemes.

Conclusion

Agricultural allied enterprises should be viewed as an alternative to mainstream nonfarm employment opportunities and although not the perfect way of providing employment to the poor in rain fed farming. agriculture, natural resources and microenterprises are interrelated livelihood areas. Various livelihood opportunities will improve the resource base which creates a more conducive environment for undertaking microenterprise activities, leading to an overall increase in standard of living, employment, poverty reduction and building resilience of the community to cope with the impacts of drought.

References

- **Anantha, K.H. , Wani, S.P. and Sreedevi, T.K. 2009.** International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Agriculture and Allied Micro-enterprise for Livelihood Opportunities.
- **Hiremath, B.N. 2007.** The Changing faces of Rural Livelihoods in India. Paper presented at the National Civil society Conference on 'What it takes to eradicate poverty' held during December 46, 2007. Institute of Rural Management, Anand, Gujarat. pp. 110.
- **Rangarao, G.V. 2009.** Agriculture and allied enterprises for Livelihood opportunities. Paper presented at the training program on 'Capacity Building for Integrated watershed Development', held at ICRISAT, Patancheru, Andhra Pradesh during 2- 27 December, 2009.
- **Reddy, R.R., Wani. S.P., Reddy M., Reddy L.T. and Koppula, P. 2008.** Medicinal and Aromatic Plants for Diversifying Semi-Arid Tropical (SAT) Systems: A Case of Public Private Partnership (PPP). Global Theme on Agro-ecosystems Report No. 44. Patancheru 502-324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.
- **Government of India. 2006.** A report on the brainstorming session on 'Apiculture in India – Problems and Prospects and Need for Biotech Interventions' under the auspices of National Bio resource Development Board of DBT, Ministry of Science and Technology, Government of India at New Delhi.

Just Agriculture Multidisciplinary *e- newsletter*

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Umesh
ICAR-Indian Institute of Pulses Research, Kanpur

Deepak Yadav
ICAR-Indian Institute of Pulses Research, Kanpur

Dr. Yogesh Kumar
ICAR-Indian Institute of Pulses Research, Kanpur

Dr. Bishwajit Mandal
ICAR-Indian Institute of Pulses Research, Kanpur

Rohit
Ranjeet Singh Institute of Education & Technology, Gungwach, Karaundi, Amethi

Dipanshu Yadav
[3]Chaudhary Charan Singh Degree College, Heowra, Itawah.

Ajay Kumar Gupta
Chaudhary Charan Singh University, Meerut

Priybrat Tripathi
Chhatrapati Shahu Ji Maharaj University, Kanpur

ARTICLE ID: 07

Global and National Scenario of Pulses Production: A comparative study of Pulses Production and Breeding Efforts in Pulses

Introduction

Pulses, the edible dry seeds of leguminous plants, have been cultivated for thousands of years. Archaeological evidence traces their origin to the Fertile Crescent, where chickpea, lentil, and pea were domesticated nearly 11,000 years ago. From this cradle of agriculture, pulses spread across Asia, Africa, and Europe, becoming integral to traditional diets and farming systems. Their ability to enrich soils through nitrogen fixation made them indispensable companions to cereals in mixed cropping.

The Food and Agriculture Organization (FAO) classifies pulses as leguminous crops harvested for dry grain. Major groups include chickpeas, lentils, dry beans, dry peas, pigeon peas, cowpeas, broad beans, Bambara beans, lupins, and vetches. They differ in seed size, shape, and colour, reflecting wide genetic diversity. Agronomically, pulses are annual crops, often grouped into cool-season (lentil, pea, chickpea) and warm-season (pigeon pea, cowpea, mung bean) types.

Pulses are grown in diverse agro-ecological zones, ranging from temperate regions to semi-arid tropics. They are typically cultivated under rainfed conditions, requiring less water than cereals. Their symbiotic association with Rhizobium bacteria enables biological nitrogen fixation, reducing fertilizer needs and improving soil fertility. Crop rotations involving pulses enhance sustainability, while intercropping with cereals stabilizes yields. India, Africa, and Latin America are major pulse-growing regions, with smallholder farmers forming the backbone of production.

Globally, pulse production exceeds 90 million tonnes annually, with India contributing nearly one-fourth. Chickpea, pigeon pea, mung bean, urad, lentil, and pea dominate Indian agriculture. Despite being the largest producer, India also imports pulses to meet domestic demand. Advances in breeding, improved varieties, and better agronomic practices have gradually increased yields, though productivity remains lower than cereals due to susceptibility to pests, diseases, and abiotic stresses.

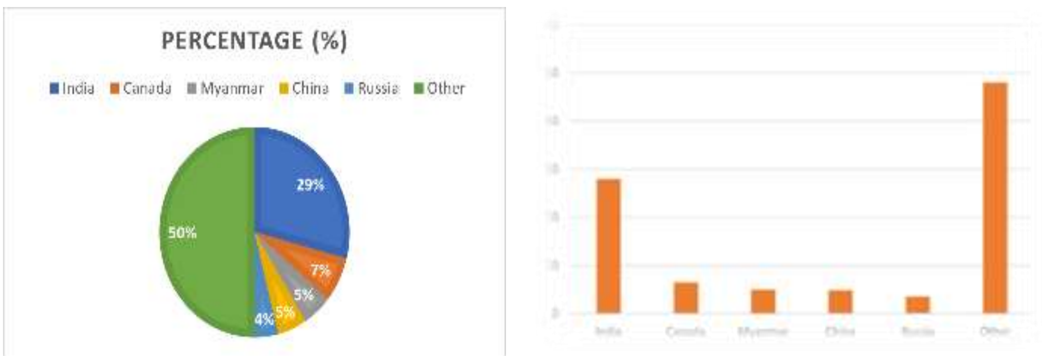


Fig. 01 Major Pulses producing countries of the World

Pulses are consumed in multiple forms—whole, split (dal), flour, or processed products. They are staples in vegetarian diets, forming the basis of curries, soups, and snacks. Beyond food, pulses serve as livestock feed and green manure. Their straw and husks are valuable by-products in mixed farming systems. Pulses also contribute to international trade, with countries like Canada and Myanmar being major exporters.

Pulses are rich in protein (20–25%), dietary fiber, complex carbohydrates, vitamins, and minerals such as iron and zinc. They are low in fat and cholesterol-free, making them vital for balanced diets. Their low glycemic index supports diabetes management, while regular consumption reduces risks of cardiovascular disease. When combined with cereals, pulses provide a complete amino acid profile, reinforcing their role as "poor man's meat" and a cornerstone of food security.

Comparison of Pulses production between last decades to till days

➢ **Global Level**

In 2015, global pulses production was estimated at around **70–75 million tonnes**, with India, Canada, Myanmar, and Australia among the leading producers. Chickpeas, lentils, and dry beans dominated cultivation, but yields were constrained by limited improved varieties, pest pressures, and reliance on rainfed systems. Farmers had little knowledge of modern techniques of crop cultivation, crop varieties developed with advance breeding tools like molecular breeding and gene editing. Trade volumes were moderate, with India importing significant quantities to meet domestic demand.

By contrast, current global pulses production has expanded to **over 90 million tonnes annually**, reflecting nearly a 20–25% increase in the past decade. Advances in breeding, improved agronomic practices, and greater awareness of pulses' nutritional and environmental benefits have driven this growth. India remains the largest producer and consumer, while Canada and Australia have strengthened their positions as major exporters. The International Grains Council reports that global pulses trade has risen by more than **30% in the last decade**, fuelled by population growth, dietary diversification, and rising demand in food processing and animal feed sectors.

Table 01 Comparison of Pulses Production with different aspects (at Global Level)

SL	Aspects	2015	2025
1.	**Estimated Production**	~70–75 million tonnes globally	~90+ million tonnes globally
2.	**Major Producers**	India, Canada, Myanmar, Australia	India, Canada, China, Myanmar and Australia
3.	**Trade Volume**	Moderate; India a key importer	Trade increased by >30% over the decade
4.	**Key Crops**	Chickpeas, lentils, dry beans and peas	Chickpeas, lentils, peas, cowpeas, pigeon peas (expanded demand)
5.	**Drivers of Growth**	Traditional diets, mixed farming systems	Improved varieties, climate-smart farming, rising health awareness
6.	**Challenges**	Low yields, pest/disease susceptibility	Climate variability, trade fluctuations, demand–supply gaps
7.	**Global Market Value**	Not widely tracked in monetary terms	USD 82.4 billion (2025 market size)

➢ **National Level**

In 2015, India produced approximately 17 million tonnes of pulses, facing challenges such as low yields, erratic rainfall, and limited access to improved varieties. Despite being the world's largest producer and consumer, India was heavily reliant on imports—particularly of tur, urad, and lentils—to meet domestic demand. The per capita availability of pulses hovered around 15–17 kg/year, below the recommended dietary intake.

Table 02 Comparison of Pulses Production with different aspects (at National Level)

SL	Aspect	2015	2025
1.	**Estimated Production**	~17 million tonnes	~25 million tonnes
2.	**Major Pulse Types**	Chickpea, pigeon pea, mungbean, urad	Chickpea, mungbean, urad, lentil (expanded area)
3.	**Cultivation Area**	~24 million hectares	~28 million hectares
4.	**Average Yield**	~700–750 kg/ha	~900–950 kg/ha
5.	**Imports**	~5.5 million tonnes	~6.7 million tonnes
6.	**Government Support**	NFSM, MSP, import subsidies	NFSM expansion, MSP hikes, buffer stock policies
7.	**Challenges**	Low productivity, erratic rainfall	Climate stress, post-harvest losses
8.	**Per Capita Availability**	~15–17 kg/year	~20–22 kg/year

By 2025, India's pulses production has risen to over 25 million tonnes, marking a significant improvement driven by government initiatives like the National Food Security Mission (NFSM), increased minimum support prices (MSP), and expansion of pulse cultivation area. Improved seed varieties, better agronomic practices, and enhanced irrigation coverage have contributed to higher productivity. However, demand continues to outpace supply, with imports projected to reach 6.7 million tonnes in FY25 due to rising consumption and stagnant yields in some regions.

The decade also saw diversification in pulse types grown, with increased emphasis on mungbean, urad, and lentil in non-traditional areas. Despite progress, India's pulse sector still faces challenges in post-harvest management, market linkages, and climate resilience. Overall, the comparison reflects a positive trajectory in production, but underscores the need for sustained efforts to achieve self-sufficiency and nutritional security.

Contribution of Breeding Strategies Pulses improvement (Breeding Efforts).

Over the past decade, breeding strategies have played a transformative role in enhancing pulses

Fig. 02 Images of Field Trials of Pulses at ICAR-Indian Institute of Pulses Research, Kanpur

production both in India and globally. In India, institutions like ICAR, ICAR-IIPR, and ICRISAT have developed high-yielding, disease-resistant, and climate-resilient varieties of chickpea, pigeon pea, mungbean, and lentil. Marker-assisted selection (MAS), genomic selection, and participatory breeding have accelerated varietal development, improving yield potential and stress tolerance. For example, drought-tolerant chickpea varieties and early-maturing heat tolerant pigeonpea varieties **(IPCL 2004-14 & ICPV25444**) have expanded cultivation into non-traditional areas, boosting national output from ~17 MMT in 2015 to ~25 MMT in 2025.

Globally, breeding programs under CGIAR and national research systems of individual country have focused on climate-smart pulses. Advances in molecular breeding, gene editing, and trait mapping have led to varieties with improved nitrogen fixation, pest resistance, and adaptability to marginal soils. Countries like Canada and Australia have adopted precision breeding and doubled their export volumes. These innovations align with UN SDGs, promoting sustainable agriculture and nutritional security.

Overall, breeding strategies have not only increased productivity but also stabilized yields under climate variability, reduced input costs, and enhanced the economic viability of pulse farming worldwide.

References:

1. Directorate of Economics and Statistics (*https://desagri.gov.in*)
2. FAO Stat. (*https://www.fao.org.in*)
3. ICAR-Indian Institute of Pulses Research, Kanpur (*https://www.icar.iipr.org.in*)
4. Indian Council of Agricultural Research, New Delhi (*https://www.icar.org.in*)
5. Koul, B., Sharma, K., Sehgal, V., Yadav, D., Mishra, M., & Bharadwaj, C. (2022).
6. Market Research Report (*https://www.imarcgroup.com*)
7. Press Information Bureau (*https://www.pib.gov.in*)

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

K. Sedhupathi

ICAR-National Research Centre for Banana, Tiruchirappalli- 620 102.

Vinodhini J

Department of Plant Pathology, Tamil Nadu Agricultural University, Coimbatore-03.

ARTICLE ID: 08

Biocontrol potential of Arbuscular Mycorrhizal Fungi against Root-Knot Nematodes

Abstract

Arbuscular mycorrhizal fungi (AMF) are obligate root symbionts that have mutualistic associations with most terrestrial plants, and thereby enhance nutrient uptake and providing protection against various biotic stresses, including plant-parasitic nematodes. Root-knot nematodes (RKN), primarily species of the genus *Meloidogyne*, are sedentary endoparasites that cause significant agricultural losses by inducing galls on plant roots by impairing water and nutrient absorption. This paper explores the biocontrol potential of AMF against RKN through mechanisms such as enhanced plant tolerance, direct competition for resources, induced systemic resistance (ISR), and altered rhizosphere interactions. The recent studies have shown that in crops like tomato, banana, and coffee demonstrats reduced nematode penetration, reproduction, and overall infestation. AMF offer a sustainable, environmentally friendly alternative to chemical nematicides, though efficacy varies with fungal species, plant genotype, soil conditions, and inoculation timing.

Introduction

Root-knot nematodes (RKN), particularly *Meloidogyne incognita* and *M. javanica*, are major agricultural pests, infecting a wide range of crops and causing significant yield losses globally (Schouteden et al. 2015). These nematodes invade plant roots, establishing feeding sites that form galls, impairing plant growth and reducing productivity in crops such as tomato, banana, and coffee (Campos, 2020). Conventional control methods such as chemical nematicides, pose environmental risks and face increasing regulatory restrictions thereby prompting exploration of biological alternatives. Arbuscular mycorrhizal fungi (AMF), from the phylum Glomeromycota, colonize the roots of approximately 80% of terrestrial plants. It is known to improve nutrient uptake and resistance to various pathogens (Schouteden et al. 2015). AMF have shown to be promising in suppression of RKN infestations by multiple mechanisms, often resulting in reduced nematode reproduction and improved plant health. This paper will provide insights on the mechanisms underlying AMF-mediated biocontrol and evaluates their practical applications.

Biology and impact of root-knot nematodes

RKNs exhibit a complex life cycle involving egg hatching, juvenile invasion, migration within roots, and establishment of feeding sites (Mbaluto et al. 2021). Infective second-stage juveniles (J2) penetrate roots in the elongation zone and induce multinucleate giant cells through pharyngeal secretions thereby causes gall formation (Bozbuga et al. 2018). This process suppresses genes for peroxidases and nutrient transporters in later infection stages (Portillo et al. 2013). Symptoms include stunted growth, wilting, and increased susceptibility to disease complexes with pathogens like *Rhizoctonia solani* in tomato damping-off or *Fusarium oxysporum* in wilt (Hadian et al. 2011). In vegetables, RKNs exacerbate issues in crops such as brinjal, carrot, and cauliflower (Junaid et al. 2013).

Seid et al. (2015) highlights RKNs' adaptability, with *M. incognita* causing persistent damage in tropical regions. A recent study on nematode-fungal interactions underscores their role in aggravating soil-borne diseases and emphasizes the need for integrated biocontrol.

Arbuscular mycorrhizal fungi: symbiosis and plant benefits

AMF was first described in 1885 (Frank, 1885), colonize the roots via spores, hyphae, or fragments and form arbuscules and vesicles for nutrient exchange (Smith and Read, 2010). They enhance phosphorus, nitrogen, zinc, and water uptake in the plant and boost biomass and root branching (Baum et al. 2015). In tomatoes, AMF improve yield, ripening, and resilience to biotic stresses like *Phytophthora parasitica*. Colonization alters root exudates, regulating symbiosis and deterring the pathogens. AMF is known for bio fortifying crops as it increases selenium in asparagus and nutrients in grains. Recent work shows AMF enhancing plant defense through metabolic changes detailing their role in growth and disease resistance via nutrient augmentation. AMF act as indirect biocontrol by improving nutrient uptake and mitigating nematode harm.

Mechanisms of AMF biocontrol against RKNs

AMF suppress RKN through a combination of direct and indirect interactions, which can be grouped into four key mechanisms:

Improved Plant Nutrition and Stress Tolerance

AMF enhance the uptake of essential nutrients, particularly phosphorus and nitrogen, which can offset the nutrient deficiencies caused by RKN infection (Campos, 2020). For example, in soybean, *Glomus* spp. mitigated damage from *M. arenaria* by improving phosphorus absorption in nutrient-poor soils (Topalović et al. 2023). Enhanced nutrition strengthens plant vigor, enabling better tolerance to nematode-induced stress. However, high soil phosphorus levels may reduce AMF colonization and efficacy (Schouteden et al. 2015).

Competitive Interactions in the Root Cortex

AMF and RKN compete for space and resources within the root cortex that often leads to reduced nematode establishment (Schouteden et al. 2015). Pre-colonization by AMF, such as *Rhizophagus irregularis*, has been shown to limit *M. incognita* penetration in tomato roots by occupying potential feeding sites (Vos et al. 2013). Additionally, AMF consume a significant portion of plant carbon (up to 20%) and potentially starving nematodes resources (Schouteden et al. 2015). Timing is critical, as prior AMF establishment is more effective than simultaneous inoculation with nematodes.

Induction of Plant Defense Responses

AMF trigger mycorrhiza-induced resistance (MIR), a form of induced systemic resistance (ISR) that primes plants for enhanced defense against RKN (Vos et al. 2013). In tomato, *Funneliformis mosseae* activates jasmonic acid (JA) and salicylic acid (SA) pathways, upregulating genes for defense enzymes like chitinases and glucanases, which reduce nematode penetration (Almutairi et al. 2025). Split-root experiments demonstrate that AMF colonization in one root section can systemically reduce *M. incognita* infection in another, highlighting the systemic nature of MIR (Vos et al. 2013).

Modification of Rhizosphere Dynamics

AMF alter root exudates, which influence nematode behavior, including hatching and root attraction (Schouteden et al., 2015). For instance, mycorrhizal tomato roots produce exudates that repel *M. incognita* and reduce infection rates (Vos et al. 2013). AMF also foster beneficial microbial communities in the rhizosphere, such as nematode-antagonistic bacteria (*Pasteuria penetrans*) and further suppress RKN populations (Campos, 2020).

Conclusion

AMF offer a sustainable, eco-friendly strategy for managing root-knot nematodes by enhancing plant resilience and directly suppressing nematode populations. Their integration into agricultural systems could reduce dependence on chemical nematicides, aligning with global sustainability goals. Future research should focus on optimizing AMF strains, improving field delivery methods, and exploring synergistic biocontrol approaches to maximize their practical impact.

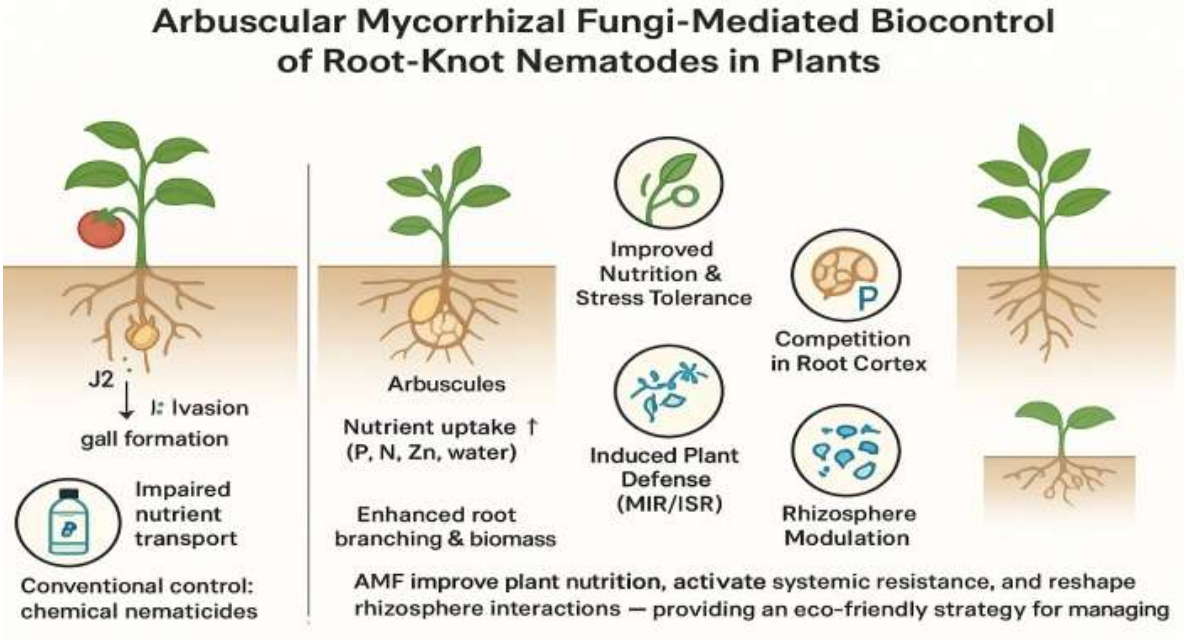


Fig.1. Graphical illustration of AMF bio control potential in managing of RKN in plants. Infective juveniles (J2) of *Meloidogyne* spp. forms galls in the invade roots, and impair nutrient transport. AMF colonize roots and forms arbuscules that enhance nutrient uptake (P, N, Zn, water) and root biomass. The bio control mechanisms include: (1) improved plant nutrition and stress tolerance, (2) competition with RKN in the root cortex, (3) induction of plant defense through mycorrhiza-induced resistance (MIR/ISR), and (4) modulation of rhizosphere dynamics and beneficial microbial interactions.

References

1. Almutairi, K., Al-Ajmi, A., & Al-Balushi, M. (2025). Mitigation of root-knot nematode infestation in tomato plants by mycorrhizal fungi. *Frontiers in Sustainable Food Systems*, 9, 123456. https://doi.org/10.3389/fsufs.2025.123456
2. Campos, H. D. (2020). Bioprotection by arbuscular mycorrhizal fungi in plants infected with *Meloidogyne* nematodes: A sustainable alternative. *Crop Protection*, 135, 105203. https://doi.org/10.1016/j.cropro.2020.105203
3. Carneiro, R., Silva, M., & Santos, L. (2020). The role of arbuscular mycorrhizal fungi against root-knot nematode infections in coffee plants. *ResearchGate*. https://www.researchgate.net/publication/342345678
4. He, L., Zhang, X., & Li, Y. (2024). Application of fungi as biological control strategies for nematode management in horticultural crops. *Phytopathology Research*, 6, 12. https://doi.org/10.1186/s42483-024-00123-4
5. Schouteden, N., De Waele, D., Panis, B., & Vos, C. M. (2015). Arbuscular mycorrhizal fungi for the biocontrol of plant-parasitic nematodes: A review of the mechanisms involved. *Frontiers in Microbiology*, 6, 1280. https://doi.org/10.3389/fmicb.2015.01280
6. Topalović, O., Hussain, M., & Vos, C. (2023). Comparative effectiveness of filamentous fungi in biocontrol of iron deficiency in soybean seedlings. *Pathogens*, 12(3), 456. https://doi.org/10.3390/pathogens12030456
7. Vos, C., Schouteden, N., van Tuinen, D., Chatagnier, O., Elsen, A., De Waele, D., & Panis, B. (2013). Mycorrhiza-induced resistance against the root-knot nematode

Meloidogyne incognita involves priming of defense gene responses in tomato. *Soil Biology and Biochemistry*, 60, 45–54. https://doi.org/10.1016/j.soilbio.2013.01.013

8. He, L., Zhang, X., & Li, Y. (2024). Application of fungi as biological control strategies for nematode management in horticultural crops. Phytopathology Research, 6, 12. https://doi.org/10.1186/s42483-024-00123-4
9. Mbaluto, C. M., Ahmad, E. M., Fu, M., Martínez-Medina, A., & van Dam, N. M. (2021). The impact of Spodoptera exigua herbivory on Meloidogyne incognita-induced root responses depends on the nematodes' life cycle stages. AoB PLANTS, 13(4), plaa029. https://doi.org/10.1093/aobpla/plaa029
10. Bozbuga, R., Lilley, C. J., Knox, J. P., & Urwin, P. E. (2018). Host-specific signatures of the cell wall changes induced by the plant parasitic nematode, Meloidogyne incognita. Scientific Reports, 8(1), 17252. https://doi.org/10.1038/s41598-018-35480-4
11. Portillo, M., Cabrera, J., Lindsey, K., Topping, J., Andrés, M. F., Emiliozzi, M., Oliveros, J. C., García-Casado, G., Solano, R., Koltai, H., Resnick, N., & Escobar, C. (2013). Distinct and conserved transcriptomic changes during nematode-induced giant cell development in tomato compared with Arabidopsis: A functional role for gene repression. BMC Genomics, 14, 759. https://doi.org/10.1186/1471-2164-14-759
12. Hadian, S., Rahnama, K., Jamali, S., & Eskandari, A. (2011). Comparing neem extract with chemical control on Fusarium oxysporum and Meloidogyne incognita complex of tomato. Advances in Environmental Biology, 5(8), 2052–2057. https://www.researchgate.net/publication/281292726
13. Seid, A., Fininsa, C., Sundh, I., & Yuen, G. Y. (2015). Plant growth promoting rhizobacteria enhance plant growth and yield of tomato under Meloidogyne incognita infestation. African Journal of Microbiology Research, 9(32), 1964–1972. https://doi.org/10.5897/AJMR2015.7536
14. Frank, A. B. (1885). Über die auf Wurzelsymbiose beruhende Ernährung gewisser Bäume durch unterirdische Pilze. Berichte der Deutschen Botanischen Gesellschaft, 3, 128–145. (No DOI available; historical reference accessible via botanical archives.)
15. Smith, S. E., & Read, D. J. (2010). Mycorrhizal symbiosis (3rd ed.). Academic Press. https://doi.org/10.1016/B978-0-12-370526-6.00001-5
16. Baum, C., El-Tohamy, W., & Gruda, N. (2015). Increasing the productivity and product quality of vegetable crops using arbuscular mycorrhizal fungi: A review. Scientia Horticulturae, 187, 131–141. https://doi.org/10.1016/j.scienta.2015.03.002

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

ARTICLE ID: 09

CARP CULTURE SYSTEMS IN ANDHRA PRADESH

AUTHORS' DETAILS:

K. Bheemeswararao, A. Chandrasekhara Rao, N. Mohana Swapna, R. S. Sravani, Shivkumar, K. Shasti Risha, P. Dheeran, T. Suguna,

Fisheries Research Station, Undi, West Godavari Dist. Andhra Pradesh Fisheries University, Andhra Pradesh

Introduction

The Kolleru Lake region in West Godavari and Krishna districts of Andhra Pradesh is renowned for its diverse carp culture systems. Among these, the semi-intensive polyculture system, commonly referred to as "Kolleru carp culture," is one of the most established and widely practiced methods. These systems evolved from traditional still-water ponds that rely on substantial feed and fertilizer inputs. Since the 1980s, this approach has been widely adopted in several Indian states, including Punjab and Tamil Nadu, as well as in Myanmar. These practices support thousands of farmers and ancillary industries, while continually adapting to challenges such as water quality management and market fluctuations.

Semi-intensive carp culture

The semi-intensive carp culture system implemented in and around Kolleru Lake, Andhra Pradesh, is commonly known as Kolleru carp culture.

- Production levels: Yields are about 7 000–10 000 kg/ha/year (often reported up to around 7.5–12.5 t/ha/year in Kolleru).
- Regional output: The Kolleru region produces on the order of several hundred thousand tonnes of carp annually (600 000–700 000 tonnes).
- Species composition and ratios: The system is dominated by two Indian major carps, rohu (*Labeo rohita*) and catla (*Catla catla*), which are stocked at approximately 80–90% rohu and 10–20% catla, with occasional minor additions of mrigal.
- System type: This is a still-water, semi-intensive pond system that relies heavily on both farm-made and commercial feeds, as well as regular fertilization to sustain natural productivity.
- Adoption and employment: This culture model has been adopted by thousands of farmers in the Kolleru region and supports a wide range of allied activities, including seed supply, feed production, labor, marketing, and transportation. As a result, the area is often referred to as a carp pocket or the "fish bowl" of India.

The Kolleru carp culture system has become the predominant production model for Indian major carp farming in India. This model has been replicated in multiple states, starting with Punjab and Haryana, and subsequently extending to Odisha, Tamil Nadu, and Karnataka. It has also been adopted in neighbouring Myanmar, where large-scale carp production units have been established. The diversity and complexity of culture systems derived from this model demonstrate the wide range of production strategies applicable to Indian major carps.

Semi-Extensive Polyculture

Semi-extensive polyculture systems, also known as initial culture systems, involve the cultivation of six carp species, including Indian major and Chinese carps. This approach was introduced in 1984.

- Species composition: Six carp species in polyculture—rohu (25–30%), catla (10–15%), mrigal (15–20%), silver carp (20–30%), grass carp (5–10%), common carp (10–20%)—optimizing different feeding niches.
- The system is defined by low stocking densities, good water quality, minimal feed inputs, and correspondingly modest production levels.
- Nutrient inputs per hectare include approximately 18,750 kg of poultry manure, 2,000 kg of cattle dung, and chemical fertilizers such as SSP (760 kg), urea (440 kg), DAP (380 kg), complex fertilizers (200 kg), and potash (220 kg).
- Stocking rates are generally 2,000–3,000 fish/ha for rohu and 250–300 fish/ha for catla, with fingerlings weighing 5–10 g.
- Supplementary feed requirements range from 4,800 to 7,200 kg/ha/year to achieve these production levels, with food conversion ratios typically between 1.8 and 2.0:1.
- At harvest, rohu reach 1–1.25 kg, while catla attain 2–2.5 kg. Annual yields are 2,000–3,000 kg/ha for rohu and 500–600 kg/ha for catla, giving a total production of 2,500–3,600 kg/ha/year.

On-Growing Semi-intensive Polyculture or typical culture or yearling-based culture.

On-growing semi-intensive polyculture systems using larger yearlings represent an advanced variant of Kolleru-style carp culture, building on the semi-extensive systems. These systems typically use stunted yearlings, hence the term *yearling-based culture*. This yearling-based approach leverages bigger initial stock for higher yields and output.

- Stock size: Uses stunted yearlings of 50–125 g, allowing faster growth to market size compared to fingerlings.
- Stocking densities: Rohu at 5,000–6,750 fish/ha; catla at 550–800 fish/ha, balancing surface (catla) and mid-bottom (rohu) feeding niches.
- Harvest sizes: Rohu typically reach 1–2 kg and catla 2–3 kg after 8–12 months, with overall production ranging from 6,600 to 8,400 kg/ha/year. Achieving these yields requires feed inputs of 17,160–26,880 kg/ha/year, resulting in feed conversion ratios (FCR) of 2.6–3.2:1.

Zero Point Culture

Semi-intensive Polyculture Fattening

In this system, rohu and catla are typically harvested at 1 kg and 2 kg, respectively. However, emergency harvests may occur when fish are smaller than 1 kg due to factors such as poor water quality, disease outbreaks, or growth issues associated with toxic phytoplankton. These prematurely harvested fish are classified as *zero-point size*, generally 200–500 g for rohu and 250–1,000 g for catla.

Farmers began acquiring healthy zero-point fish from other producers and rearing them for an additional 6–7 months. This system has proven advantageous, particularly for those with facilities designed to produce stock for zero-point culture.

- The primary advantage of zero-point culture is the potential for faster economic returns and the production of larger fish, which are preferred by consumers.
- Stocking densities are generally 5,000–6,000 fish/ha, lower than typical semi-intensive systems, with production levels of 8,000–10,000 kg/ha/year and FCRs of 2.5–3.2:1.
- Feed and management practices largely mirror those of typical culture systems.

Semi-intensive Juvenile Polyculture or Zero Point Stock Culture

The emergence of zero-point culture has led to the development of a new group of farmers specializing in the production of zero-point rohu and catla stock for grow-out operations. Typically, this system is adopted by farmers with 2–4 hectares of ponds and access to freshwater. Feeding and fertilization are limited, resulting in fish relying primarily on natural productivity, with fertilization applied to enhance pond productivity and natural food availability.

- Stocking: Fingerlings (5–10 g); rohu 20,000–25,000/ha; catla 1,500–2,000/ha.
- Cycle: ~120 days per crop, 3–4 cycles/year.
- Feeding: Farmers reduce feed costs by primarily using rice bran, supplementing with oil cakes during the later stages of culture.
- Fertilization: Applied to boost pond productivity and natural food availability.
- Yields: 8,000–12,000 kg/ha/year total (sold as zero-point stock at ~INR 40–50/kg).

Polyculture with Indian major carps, black tiger shrimp and giant river prawns

In East Godavari district, Andhra Pradesh, Indian major carps have been cultured either as the primary crop or in combination with black tiger shrimp. Since 2000, combinations of Indian major carps and giant river prawns have also been implemented in Nellore and East Godavari districts. Due to the tolerance of tiger shrimp for brackish water and the ability of Indian major carps and river prawns to thrive in freshwater, these species can be co-cultured at salinities up to approximately 10 ppt.

- IMCs and Black tiger shrimp (*Penaeus monodon*): East Godavari; shrimp as primary/secondary crop in brackish-freshwater ponds (salinity up to 10 ppt).
- IMCs and Giant River prawn (*Macrobrachium rosenbergii*): Nellore/East Godavari; prawns thrive in freshwater to low salinity.
- Converted shrimp ponds: West Godavari brackish ponds (1–10 ppt) converted for IMCs or striped catfish (*Pangasianodon hypophthalmus*)

Semi-intensive polyculture with Indian major carps and exotic fish

In 1995, farmers in Andhra Pradesh began incorporating two species, striped catfish (*Pangasianodon hypophthalmus*) and Roopchand (*Piaractus brachypomus*), into Indian major carp polyculture systems due to their relatively high growth rates and productivity. Subsequently, both species were successfully cultured in monoculture. Currently, polyculture systems often combine Indian major and Chinese carps with either striped catfish or Roopchand.

Striped Catfish

Introduced in 1995 using seed from Bangladesh via West Bengal, striped catfish transitioned from a supplement in Indian major carp polyculture to a dominant monoculture species, driven by its rapid growth potential (7–50 t/ha/year).

- Current production: Approximately 400,000 tonnes/year, stabilizing post-boom but still.
- Adoption: Striped catfish monoculture has proven more profitable than polyculture and now occupies 7–8% of the total fish culture area. The establishment of local hatcheries has reduced dependence on imported seed.

Roopchand

Roopchand was introduced in 2008 in West Godavari and has since expanded to Krishna and East Godavari districts. It is now cultured in polyculture systems with Indian major carps, Chinese carps, and striped catfish.

Traits: Roopchand exhibits rapid growth, reaching market size within 4–6 months. It is a feed-efficient and hardy species, suitable for polyculture systems with yields of 10–13 t/ha.

Just Agriculture Multidisciplinary *e- newsletter*

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Vipin Tanwar
M.Sc. Scholar, Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir, India

B.R. Bazaya
Professor, Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir, India

A.P. Singh
Professor & Head, Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir, India

Raju Gupta
SMS (Agronomy), Krishi Vigyan Kendra, Ramban, Jammu and Kashmir, India

Bhim Singh
Ph.D. Scholar, Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir, India

ARTICLE ID: 10

Parthenium: Effects and Management

Introduction

Parthenium (*Parthenium hysterophorus* L.) is commonly known as Congress or carrot grass, is an invasive annual weed belongs to Asteraceae family. It is a native of tropical America but widely spread across India and many other different countries due to its rapid growth, higher seed production and adaptable to different climates. It is commonly spread into agricultural fields, roadsides, grazing lands and wastelands. This weed thrives well in both favourable and unsuitable conditions, making its control most difficult. It's strong allelopathic effect and ability to outcompete the native natural vegetation and agricultural crops making it one of the most dominant and problematic weed in today's era.

Why to manage this weed ?

This weed should be effectively managed due to its rapid spread and serious impacts on agriculture, human health and environment. It significantly reduces the yield of crops by competing for nutrients, space and light which also causes health hazards in human and animals. If it left uncontrolled, it can dominate fields and natural ecosystem, leading to loss of biodiversity and agricultural crops.

Source: Sharma *et al.*, 2015

Its harmful effects:

1. Effect on crops

This weed is highly aggressive in nature which reduces the growth and yield of crop by competing with them for resources. Its fast growth and densely spreading hinder proper crop establishment. In addition, it also releases allelopathic chemicals into the soil, which can inhibit seed germination and root deveopment of neighbouring crops. The severe infestation of this weeds leads to considerable loss in yield reduction, increases difficulty in field operations and raises the overall cost of cultivation.

2. Effect on human health

This causes the serious health problems in human beings. As direct contact of this weed leads to rashes, dermatitis and other respiratory problems. Its pollen and dust may cause the respiratory problems such as asthma, bronchitis and eye irritation to the agricultural workers. The prolonger exposure of this weed can make the lungs older than the normal age and also cause the severe allergic problems.

3. Effect on livestock

This weed is also toxic for the livestock when ingested by them with fodder. It can cause the loss of apetite, mouth ulcers and digestive problems which affect the overall health of animals. The prolonged feeding of this weed with fodder may reduce the yield and quality of milk. The heavy infestation of this weed in grazing areas reduce the availablity of safe and nutritious fodder for animals.

4. Effect on biodiversity

This weed possess a serious threat to the environment as it spreads vigorously in wastelands, open areas and roadsides. This reduces the biodiversity and affects the natural ecosystem. Its presence can change the natural vegetation pattern and make the land unsuitable for other plants and grazing animals. The dense growth of this weed also degrades the pasture land by reduces their soil fertility and affecting long term land productivity.

It's beneficial effects:

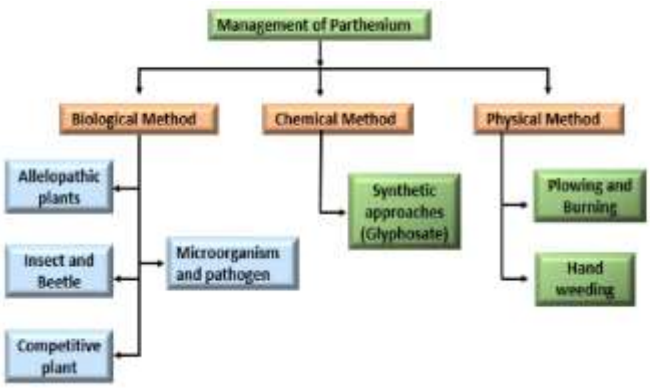
a. Green manure: This can be used as a green manure crop after proper treatment and decomposition. When it is incorporating into the soil, it add the organic matter, improve soil structure and enhance the nutrient content which directly helps in the crop growth. This helps in maintaining the soil fertility and reduce the usage of chemical fertilizers. However, due to its toxic and allergic property, the careful handling is essential to prevent the health risks to humans and animals.

b. Cover crops: This can be used as a cover crops in degraded or open areas. Its dense growth protects the soil from erosion and prevents water runoff. It also supress the growth of other weeds. The proper management is necessary to control its spread and avoids other environmental and health risks.

c. Biogas production: This can also used as a raw material for biogas production due to its rapid production of biomass. This biomass can be converted into methane gas which serves as a renewable energy source. This approach helps in managing their large weed population and also provides an eco-friendly alternative to conventional fuels.

d. Medicinal and Research uses: This weed contains the several bioactive compounds which shows anti-microbial and pesticidal properties. It's extracted compounds are also studied for the production of bio-herbicides and natural pesticides. Some researches explores its potential in traditional medicines, although its direct use is harmful due to its toxicity. The proper handling is necessary for avoiding health risks during research and processing.

e. Composting: This weed can be converted into compost after proper treatment. The proper compost made from this weed is adding the nutrients and organic matter into the soil which supports crop growth and reducing weed competition. The careful handling is necessary to avoid allergic reactions and health risks during the process.



Source: Bashar *et al.*, 2021

Management strategies:

a. Physical control

This involves the manually removing of this weed from fields, roadsides and wastelands to prevent its spread to other areas. In this control strategy, the uprooting of weeds should be done before flowering to prevent seed formation. The removed weeds should be collected and safely disposed to one place. The regular monitoring of fields and wastelands is very important to check the regrowth of that weed.

b. Chemical control

This involves the use of chemical herbicides to kill or suppress this weed. The various pre and post emergence herbicides were used such as Glyphosphate and 2,4-D to control this weed. The spraying should be done with proper care to avoid harm to crops, animals and humans. The application of herbicides should be done with correct recommended dose and following proper safety precautions.

c. Mechanical control

This involves the cutting, mowing or slashing the plant parts of this weed to prevent flowering and seed production. This can be done by using the tools, machinery or manual equipment. The regular cutting of this weed helps in achieving the lower weed population and stops its further desemination. The removed plants should be collected and safely disposed to avoid regrowth.

d. Cultural control

This involves the various farming practices to suppress this weed naturally. This includes the growing of dense crops, crop rotation, intercropping and maintaining proper land management. These practices reduce the sunlight, nutrients and space for this weed. The proper management of the cropping field also helps to prevent its desemination and reduce their population.

e. Biological control

This method is using the natural enemies to suppress the growth of this weed. In this leaf-feeding beetle (*Zygogramma bicolorata*), stem galling mite (*Aceria sphaerocephala*), fungus (*Fusarium spp.*) and the parasitic plant (*Cuscuta spp.*) were used to manage this weed. These organisms feed on, infect the weed, reducing its growth and seed production. When properly applied, this control method is an environmentally safe and effective method for manage this weed.

f. Awareness programmes

This can help people to understand the harmful effects and control strategies to manage this weed. The activities like campaigns, training and field demonstrations encourage the community participation. The increased awareness ensures the better management and reduce the spread of this weed.

Conclusion

Parthenium is a highly invasive weed that harms human health, crop production and biodiversity. Although it has limited beneficial uses, its harmful effects are far greaterand require immediate action. Its spread can be controlled through awareness, safety measures and integrated management practices. The coordinated action by farmers, researchers and communities can help to reduce its spread and protecting agriculture and environment.

References

- Bashar, H.M.K., Juraimi, A.S., Ahmad-Hamdani, M.S., Uddin, M.K., Asib, N., Anwar, M.P., & Rahaman, F. (2021). A mystic weed, Parthenium hysterophorus: Threats, potentials and management. Agronomy, 11(8), 1514.
- Singh, S., Khandpur, S., & Sharma, V.K. (2015). Allergic contact dermatitis to Parthenium hysterophorus mimicking actinic prurigo. Indian Journal of Dermatology, Venereology and Leprology, 81(1), 82-84

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Ashutosh Bharat Gawande

Young Professional, Indian Council of Agricultural Research (ICAR) – Central Institute for Cotton Research, Nagpur-441108, India

ARTICLE ID: 11

Electrospun Nanofibers for Wastewater Treatment

Abstract
The global escalation of water pollution driven by industrialization, agricultural runoff, and urbanization has intensified the need for advanced materials capable of efficiently removing diverse contaminants from aquatic systems. Electrospinning has emerged as a powerful fabrication technique for producing nanofibrous membranes with unique structural and physicochemical properties suitable for wastewater remediation. Electrospun nanofibers exhibit high surface-area-to-volume ratios, interconnected porous structures, and tunable surface functionalities that enable efficient pollutant capture through adsorption, catalytic degradation, and selective filtration mechanisms. This review provides a comprehensive overview of electrospinning technology and its applications in wastewater treatment, focusing on heavy metal removal, photocatalytic degradation of organic pollutants, oil–water separation, and antimicrobial water purification. The influence of electrospinning parameters on fiber morphology and membrane performance is discussed alongside recent advancements in surface functionalization strategies. Despite promising laboratory results, challenges including membrane fouling, mechanical stability, and scalability remain barriers to industrial implementation. Future research directions emphasize hybrid nanostructures, sustainable polymers, and scalable electrospinning technologies to facilitate large-scale environmental applications.
Keywords: Electrospinning; Nanofibrous membranes; Wastewater treatment; Heavy metal removal; Photocatalysis; Oil–water separation; Nanocomposite membranes; Water purification.

1. Introduction

Water pollution has become one of the most pressing environmental challenges worldwide, threatening ecosystems, public health, and economic development. Industrial effluents, agricultural pesticides, pharmaceutical residues, and heavy metal ions frequently contaminate water resources, creating complex mixtures of pollutants that are difficult to remove using conventional treatment methods (Uddin et al., 2022; Ji et al., 2023). Traditional processes such as coagulation, sedimentation, and biological treatment often exhibit limited efficiency for persistent pollutants and emerging contaminants (Nayl et al., 2022; Kumar et al., 2024). Nanotechnology has emerged as a promising approach for improving water purification technologies due to the unique properties of nanoscale materials. Among these, electrospun nanofibrous membranes have attracted significant attention for wastewater treatment because of their high porosity, tunable surface chemistry, and interconnected pore structures (Agrawal et al., 2021; Han et al., 2024). Electrospinning is a versatile technique capable of producing ultrafine fibers ranging from tens of nanometers to several micrometers using electrostatic forces applied to polymer solutions or melts (Jahan & Zhang, 2022; Yilmaz & Soylak, 2021).

The resulting nonwoven fiber mats possess a large specific surface area and hierarchical porous structures that enhance contaminant adsorption, catalytic activity, and filtration efficiency (Mondal, 2017; Wang et al., 2025). These characteristics make electrospun membranes highly suitable for applications including heavy metal removal, dye degradation, oil–water separation, and pathogen inactivation (Sekar & Manickam, 2018; Serik et al., 2024). Recent developments have focused on integrating functional nanoparticles such as titanium dioxide, graphene oxide, metal–organic frameworks, and carbon nanotubes within electrospun fibers to enhance adsorption capacity and catalytic activity (Lv et al., 2023; Ahmadijokani et al., 2022). Hybrid electrospun materials have demonstrated improved performance in removing complex contaminants from wastewater streams. This article discusses the fundamental principles of electrospinning technology, the structural advantages of electrospun membranes, and their diverse environmental applications. Emphasis is placed on understanding how fabrication parameters influence membrane performance and how surface modification strategies can enhance pollutant removal efficiency.

2. Fundamentals of Electrospinning Technology

2.1 Electrospinning Process and Fiber Formation

Electrospinning is a fiber fabrication technique that uses high electrostatic forces to produce continuous polymer fibers with nanoscale diameters. The basic electrospinning setup typically includes a high-voltage power supply, a syringe pump, a spinneret, and a grounded collector (Agrawal et al., 2021; Nayl et al., 2022). When high voltage is applied to the polymer solution at the spinneret tip, electrostatic forces overcome the surface tension of the droplet, forming a conical shape known as the Taylor cone. A charged jet is then ejected from the cone and undergoes elongation and whipping instability before depositing onto the collector as ultrafine fibers (Uddin et al., 2022; Han et al., 2024). The morphology and properties of electrospun fibers are strongly influenced by several parameters including polymer concentration, viscosity, electrical conductivity, applied voltage, flow rate, and tip-to-collector distance (Ji et al., 2023; Yilmaz & Soylak, 2021). Solution viscosity is particularly critical; low viscosity leads to bead formation while excessive viscosity inhibits jet formation (Kumar et al., 2024). Environmental factors such as humidity and temperature also play important roles in fiber formation. High humidity levels may induce pore formation due to phase separation mechanisms, resulting in porous fiber structures that enhance adsorption capacity (Cao et al., 2022; Wang et al., 2025).

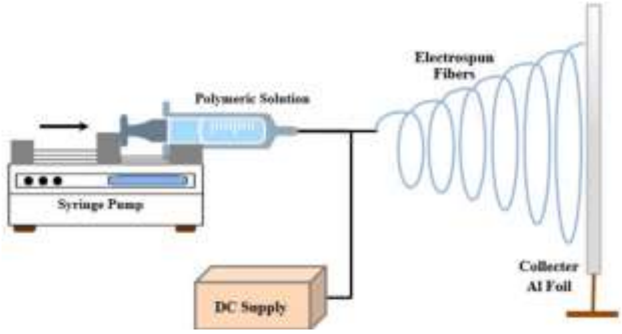


Figure 1. Schematic view of electrospinning process (*Asmatulu ,2016*)

2.2 Structural Advantages of Electrospun Nanofibrous Membranes

Electrospun membranes possess unique structural features that differentiate them from conventional filtration materials. Their high porosity and interconnected pore networks enable efficient mass transfer and low pressure drop during filtration processes (Jahan & Zhang, 2022; Ji et al., 2023). The extremely high surface-area-to-volume ratio of electrospun fibers provides abundant active sites for adsorption and catalytic reactions, making them effective platforms for removing dissolved pollutants (Serik et al., 2024; Lv et al., 2023). Additionally, the nanoscale fiber diameter increases the probability of particle interception and diffusion, improving filtration efficiency for submicron contaminants (Mondal, 2017; Wang et al., 2025). Electrospun membranes can also be engineered with various structural architectures, including core-shell fibers, porous fibers, and aligned fiber arrays, enabling precise control over membrane properties (Sekar & Manickam, 2018; Ahmadijokani et al., 2022).

3. Applications of Electrospun Nanofibers in Wastewater Treatment

3.1 Heavy Metal Removal

Heavy metals such as lead, chromium, cadmium, and arsenic are highly toxic contaminants commonly found in industrial wastewater. These metals are persistent and bioaccumulative, posing serious threats to ecosystems and human health (Uddin et al., 2022; Mittal & Kushwaha, 2024). Electrospun nanofibers provide efficient platforms for heavy metal adsorption due to their large surface area and tunable surface chemistry (Nayl et al., 2022; Ji et al., 2023). Functional groups such as amine, hydroxyl, and carboxyl groups can be introduced onto fiber surfaces to enhance metal ion binding through chelation and electrostatic interactions (Yilmaz & Soylak, 2021; Han et al., 2024). Recent research has demonstrated that electrospun membranes incorporating metal–organic frameworks exhibit exceptionally high adsorption capacities for heavy metal ions due to their highly porous structures and tunable pore chemistry (Ahmadijokani et al., 2022; Kumar et al., 2024). Composite nanofibers containing metal oxide nanoparticles have also been shown to improve adsorption performance and catalytic reduction of toxic metal ions (Lv et al., 2023; Jianxin et al., 2024).

3.2 Photocatalytic Degradation of Organic Pollutants

Organic pollutants such as dyes, pharmaceuticals, and pesticides represent another major category of wastewater contaminants. Many of these compounds are resistant to biological degradation and require advanced oxidation processes for removal (Serik et al., 2024; Cao et al., 2022). Electrospun nanofibers embedded with photocatalytic nanoparticles such as TiO_2 and ZnO have demonstrated significant potential for degrading organic pollutants under light irradiation (Marinho et al., 2021; Lv et al., 2023). These photocatalytic systems generate reactive oxygen species that oxidize organic molecules into harmless byproducts (Serik et al., 2024). Hybrid nanofibers containing graphene derivatives and noble metal nanoparticles have been shown to enhance photocatalytic efficiency by improving charge separation and light absorption (Cao et al., 2022; Wang et al., 2025). Electrospun photocatalytic membranes also offer advantages over suspended catalysts because they allow easy recovery and reuse of catalysts, reducing secondary contamination risks (Lu et al., 2021; Kumar et al., 2024).

3.3 Oil–Water Separation

Oil contamination in wastewater is a major issue in industries such as petroleum refining, food processing, and metal machining. Electrospun membranes with engineered surface wettability have shown exceptional performance in oil–water separation (Yan et al., 2021; Su et al., 2022). Superhydrophobic super-oleophilic membranes allow oil to permeate while repelling water, whereas super-hydrophilic membranes exhibit the opposite behavior (Su et al., 2022; Chaithra et al., 2024). These wettability properties can be controlled through surface modification or nanoparticle incorporation. Electrospun nanofiber membranes have demonstrated high separation efficiencies exceeding 99% for oil-water mixtures due to their hierarchical surface roughness and high permeability (Yan et al., 2021; Lu et al., 2021).

3.4 Antimicrobial Water Purification

Microbial contamination in water supplies poses significant risks to public health. Electrospun nanofibers can incorporate antimicrobial agents such as silver nanoparticles, graphene oxide, and quaternary ammonium compounds to inhibit bacterial growth (Agrawal et al., 2021; Wang et al., 2025). These antimicrobial membranes provide dual functionality by physically filtering microorganisms and chemically inactivating pathogens through reactive oxygen species or metal ion release (Jahan & Zhang, 2022; Han et al., 2024).

4. Surface Modification Strategies

Surface modification plays a critical role in enhancing the functionality of electrospun membranes. Techniques such as plasma treatment, chemical grafting, and nanoparticle deposition are commonly used to introduce functional groups and improve membrane performance (Ji et al., 2023; Kumar et al., 2024). Plasma treatment increases surface hydrophilicity and improves membrane wettability, which enhances filtration performance (Cao et al., 2022). Meanwhile, chemical grafting allows the attachment of functional molecules that enhance adsorption selectivity for specific contaminants (Serik et al., 2024). Incorporating metal–organic frameworks or photocatalytic nanoparticles onto electrospun fibers creates multifunctional membranes capable of simultaneously adsorbing and degrading pollutants (Ahmadijokani et al., 2022; Lv et al., 2023).

5. Challenges and Future Perspectives

Despite their promising performance, electrospun membranes face several challenges that limit their widespread industrial adoption. Mechanical stability remains a key concern due to the fragile nature of ultrafine nanofibers (Uddin et al., 2022; Han et al., 2024). Scalability is another major challenge because conventional electrospinning systems have relatively low production rates compared to industrial membrane fabrication methods (Ji et al., 2023; Wang et al., 2025). Membrane fouling caused by the accumulation of organic matter and microorganisms can also reduce filtration efficiency over time (Nayl et al., 2022; Kumar et al., 2024). Future research should focus on developing robust composite membranes, scalable electrospinning technologies, and sustainable bio-based polymers to enhance environmental compatibility (Jahan & Zhang, 2022; Mittal & Kushwaha, 2024).

6. Conclusion

Electrospinning technology has emerged as a versatile platform for the fabrication of advanced nanofibrous membranes for wastewater treatment. The unique structural properties of electrospun fibers including high surface area, tunable porosity, and flexible surface chemistry enable efficient removal of heavy metals, organic pollutants, oils, and microbial contaminants. Recent advances in hybrid nanomaterials and surface functionalization have significantly improved membrane performance, paving the way for multifunctional water purification systems. However, challenges related to scalability, durability, and membrane fouling must be addressed to enable large-scale implementation. Continued interdisciplinary research integrating materials science, environmental engineering, and nanotechnology will be essential to realize the full potential of electrospun nanofiber membranes in sustainable water treatment technologies.

References

1. Agrawal, S. (2021). Synthesis and water treatment applications of nanofibers by electrospinning. *Processes*, *9*(10), 1779. https://www.mdpi.com/2227-9717/9/10/1779
2. Ahmadijokani, F. (2022). Metal–organic frameworks and electrospinning: a hybrid platform for wastewater treatment. *Advanced Functional Materials.* https://doi.org/10.1002/adfm.202207723
3. Alias, N. H. (2019). Photocatalytic nanofiber-coated membranes for oilfield produced water treatment. *Chemical Engineering Journal.* https://doi.org/10.1016/j.cej.2018.11.
4. Asmatulu, R.. (2016). Highly Hydrophilic Electrospun Polyacrylonitrile/ Polyvinypyrrolidone Nanofibers Incorporated with Gentamicin as Filter Medium for Dam Water and Wastewater Treatment. Journal of Membrane and Separation Technology. 5. 38-56. 10.6000/1929-6037.2016.05.02.1.
5. Cao, X. (2022). Electrospun porous nanofibers: pore-forming mechanisms and applications in wastewater photocatalysis. *Polymers*, *14*, 3990. https://www.mdpi.com/2073-360/14/19/3990
6. Chaithra, K. P. (2024). Electrospun membranes incorporated with metal oxide nanoparticles for wastewater treatment. *Chemical Engineering Journal.* https://doi.org/10.1016/j.cej.2024.
7. Han, L. (2024). Electrospinning nanomaterials: a powerful strategy for wastewater treatment applications. *Reviews in Environmental Science and Biotechnology.* https://doi.org/10.1007/s11157-024-09686-3
8. Jahan, I. (2022). Natural polymer-based electrospun nanofibrous membranes for wastewater treatment. *Journal of Polymers and the Environment.* https://doi.org/10.1007/s10924-021-02312-1
9. Ji, K. (2023). Research progress of water treatment technology based on nanofiber membranes. *Polymers*, *15*(3), 741. https://www.mdpi.com/2073-4360/15/3/741

10. Lu, W. (2021). Cellulose-based electrospun nanofiber membrane with photocatalytic activity for oil emulsion separation. *Carbohydrate Polymers*. https://doi.org/10.1016/j.carbpol.2021.118
11. Marinho, B. A. (2021). Electrospun TiO_2 nanofibers for water and wastewater treatment: A review. *Journal of Materials Science*. https://doi.org/10.1007/s10853-020-05610-6
12. Nayl, A. E. A. A. (2022). Review of the recent advances in electrospun nanofibers applications in water purification. *Polymers, 14*(8), 1594. https://www.mdpi.com/2073-4360/14/8/1594
13. Serik, A. (2024). Recent progress in photocatalytic applications of electrospun nanofibers. *Molecules, 29*(20), 4824. https://www.mdpi.com/1420-3049/29/20/4824
14. Su, Y. (2022). Advanced electrospun nanofibrous materials for efficient oil/water separation. *Advanced Fiber Materials*. https://doi.org/10.1007/s42765-022-00158-3
15. Uddin, Z. (2022). Recent trends in water purification using electrospun nanofibrous membranes. *International Journal of Environmental Science and Technology*. https://doi.org/10.1007/s13762-021-03603-9
16. Xu, Z. (2025). Electrospun PVDF membranes for removal of dyes and heavy metals in wastewater treatment. *Chemical Engineering Science*. https://doi.org/10.1016/j.ces.2025.
17. Yan, X. (2021). Electrospinning nanofibers and nanomembranes for oil/water separation. *Journal of Materials Chemistry A.* https://doi.org/10.1039/D1TA05873H

Just Agriculture Multidisciplinary *e- newsletter*

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

P. Shivani

M.F. Sc, Division of Aquaculture, ICAR-Central Institute of Fisheries Education, Mumbai-400061

ARTICLE ID: 12

India's 2,800 Native Treasures: The Strategic Shift to Indigenous Fish Species for a Sustainable Blue Economy

Introduction

India's aquatic ecosystems harbour over 2,800 indigenous fish and shellfish species, yet aquaculture production remains concentrated on a handful of major carps and exotic shrimp. This narrow focus not only underutilizes the country's rich aquatic biodiversity but also overlooks species with high consumer preference and regional economic importance. Many indigenous species possess traits such as disease resistance, adaptability to local climatic conditions, and the ability to thrive in low-input farming systems - making them ideal candidates for sustainable aquaculture expansion in rural India.

In January 2026, the Ministry of Fisheries announced a landmark policy shift to prioritize 11 indigenous fish species under the Blue Revolution. These species were selected based on rigorous criteria including established breeding technologies, market demand, and ecological suitability across different regions. The move aligns with the government's commitment to the Sustainable Development Goals (SDGs), particularly SDG 1 (No Poverty) and SDG 14 (Life Below Water), by promoting climate-resilient aquaculture practices that benefit smallholder farmers and conserve aquatic biodiversity.

The timing of this policy shift is critical. With climate change altering water availability and temperature regimes across the country, indigenous species offer a natural advantage – they are already adapted to local environmental fluctuations. Unlike exotic species that may require imported feed and intensive management, native fishes like Pengba (*Osteobrama belangeri*) in Manipur or Pabda (*Ompok bimaculatus*) in Tripura have coexisted with local ecosystems for centuries. Promoting their cultivation can restore ecological balance while generating livelihood opportunities in some of India's most resource-poor regions.

India's Indigenous Fish Wealth

According to ICAR–National Bureau of Fish Genetic Resources (NBFGR), India is home to:

Environment	Number of Indigenous Species
Freshwater	917 species
Brackishwater	394 species
Marine	1,548 species

While breeding technologies exist for over 80 commercially important species, adoption remains limited.

The 11 Priority Indigenous Species

S.No.	Scientific Name	Common Name	Environment
1.	*Labeo fimbriatus*	Fringed-lipped Carp	Freshwater
2.	*Systomus sarana*	Olive Barb	Freshwater
3.	*Osteobrama belangeri*	Pengba	Freshwater
4.	*Channa striata*	Striped Murrel	Freshwater
5.	*Ompok bimaculatus*	Pabda	Freshwater
6.	*Heteropneustes fossilis*	Singhi	Freshwater
7.	*Lates calcarifer*	Asian Seabass	Brackishwater
8.	*Etroplus suratensis*	Pearlspot (Karimeen)	Brackishwater
9.	*Trachinotus spp.*	Pompano	Brackishwater/Marine
10.	*Scylla spp.*	Mud Crab	Brackishwater
11.	*Penaeus indicus*	Indian White Shrimp	Brackishwater

The Department of Fisheries, Government of India, along with ICAR, has prioritized the following indigenous species based on economic significance, market demand, and regional importance:

These species have established breeding, seed production, and farming technologies, making them ready for large-scale adoption.

Why Promote Indigenous Fish Species?

Ecological Benefits

Indigenous species are naturally adapted to local ecosystems, contributing to ecological stability and reducing risks associated with invasive species. Maharashtra's recent stocking of 1.22 crore indigenous fingerlings in Ujani Reservoir reduced invasive Tilapia populations by 30-40%.

Economic and Livelihood Advantages

Local communities depend on these species for income and region-specific markets. They are highly valued in local and regional markets and can significantly contribute to aquaculture production.

Cultural Significance

These species reflect deep connections between communities and their aquatic environments, forming integral parts of regional cuisines, festivals, and traditional fishing practices.

Labeo fimbriatus

Systomus sarana

Osteobrama belangeri

Ompok bimaculatus

Etroplus suratensis

Penaeus indicus

Reduced Dependency on Exotic Species

Diversification reduces vulnerability to disease outbreaks and market fluctuations that can devastate monocultures.

Government Support: A Comprehensive Approach

The Department of Fisheries is enabling aquaculture diversification through key schemes:

Scheme	Full Form	Support Provided
PMMSY	Pradhan Mantri Matsya Sampada Yojana	1.50–60% subsidy for indigenous species hatcheries & ponds 2.Genetic improvement of priority species 3.Supports 34 indigenous species clusters
PMMKSSY	Pradhan Mantri Matsya Kisan Samridhi Sah-Yojana	1.Free seed delivery & input support 2.Farmer training & KCC linkages
FIDF	Fisheries and Aquaculture Infrastructure Development Fund	1.Low-interest loans for breeding units 2.Funding for nurseries, feed mills, cold chains

Genetic Improvement Initiatives

The DoF has selected several species for genetic enhancement programs, including Scampi, Rohu, Catla, Murrel, *Penaeus indicus*, *Penaeus monodon*, and Indian Pompano. Two Nucleus Breeding Centres (NBCs) have been sanctioned:

- **Freshwater NBC** at ICAR–CIFA, Bhubaneswar
- **Marine NBC** at ICAR–CMFRI, Mandapam

These centres will produce high-health, genetically improved seed for commercial-scale aquaculture.

34 Regional Clusters for Indigenous Species

The DoF has notified 34 production and processing clusters across India:

Cluster Location	Species Focus
Odisha	Scampi
Telangana	Murrel
Tripura	Pabda
Manipur	Pengba
Jammu & Kashmir and Ladakh	Trout
Kerala	Pearlspot
Karnataka	Marine cage farming
Madurai	Ornamental fish

These clusters will enhance production, processing, and marketing while generating employment for rural women and youth.

Addressing Knowledge Gaps

A significant challenge remains: lack of awareness and technical knowledge among farmers about indigenous species. Strengthening capacity through training, demonstrations, and extension services is crucial for large-scale adoption.

Initiatives like the WorldFish project "Taking Nutrition-Sensitive Carp–SIS Polyculture Technology to Scale," funded by GIZ, have demonstrated success in developing mass seed production protocols for small indigenous fish species.

Conclusion

India's aquaculture future lies in its native waters. With over 2,800 species available, 11 priority species ready for immediate adoption, 34 clusters established, and comprehensive government support through PMMSY, PMMKSSY, and FIDF, farmers have both opportunity and incentive to diversify. By leveraging the ecological, economic, and cultural value of native species, India is paving a path toward sustainable aquaculture growth - ensuring food security, improving rural incomes, and preserving aquatic heritage for generations to come. The time to look beyond rohu-catla and explore India's native treasures is now.

References

- Ministry of Fisheries, Animal Husbandry and Dairying, Government of India. (2026). India pushes indigenous fish species to strengthen sustainable aquaculture. *Press Release, January 2*. New Delhi.
- ICAR-National Bureau of Fish Genetic Resources. (2026). Indigenous fish diversity of India: Freshwater, brackishwater and marine species. *NBFGR Technical Bulletin*. Lucknow.
- Department of Fisheries, Government of India. (2026). Priority indigenous species for aquaculture diversification under Blue Revolution. *Policy Document*. New Delhi: DoF.
- WorldFish India and GIZ. (2025). Tiny treasures, big impact: The vital role of small indigenous fish species in nutrition and livelihoods. *Photographic Anthology*. Bhubaneswar: WorldFish.
- *Hindustan Times*. (2026, February 21). Maharashtra releases 1.22 crore indigenous fingerlings into Ujani reservoir. Mumbai: HT Media.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Dr. B. Sampath Kumar

Associate Professor, Department of Veterinary Biochemistry, College of Veterinary Science, Rajendra Nagar, Hyderabad 500030, PVNRTVU

ARTICLE ID: 13

DIAGNOSTIC LANDSCAPE OF POULTRY VIRAL DISEASES: FROM CONVENTIONAL TO ADVANCED FRONTIERS

Abstract

The poultry sector is a major contributor to global food security and rural livelihoods. However, viral diseases such as Newcastle disease, avian influenza, infectious bursal disease, and infectious bronchitis continue to threaten poultry production worldwide. Rapid and accurate diagnosis is essential for effective disease control and prevention of economic losses. Over the past few decades, diagnostic technologies have evolved from simple clinical observations and serological tests to advanced molecular and genomic tools. Traditional methods such as haemagglutination inhibition and ELISA remain important for monitoring flock immunity, while modern techniques including RT-PCR, loop-mediated isothermal amplification (LAMP), and next-generation sequencing provide rapid and highly sensitive detection of viral pathogens. Environmental monitoring and artificial intelligence-based disease prediction systems are further revolutionizing poultry health surveillance. This article reviews the diagnostic spectrum of poultry viral diseases and highlights how integrating conventional and advanced diagnostic methods can improve disease detection and biosecurity in modern poultry farming systems.

1. Introduction

The poultry industry is one of the fastest-growing sectors of animal agriculture and plays a crucial role in providing affordable animal protein through meat and eggs. India is among the leading producers of poultry products, and the sector continues to expand rapidly with the adoption of improved breeds, intensive production systems, and modern management technologies. However, poultry farms remain highly vulnerable to infectious diseases, particularly viral infections, due to factors such as high stocking density, rapid turnover of birds, intensive management practices, and frequent movement of birds, workers, and equipment. The pathogens can spread rapidly within flocks, resulting in high mortality, reduced egg production, poor growth performance, and substantial economic losses. Therefore, early and accurate diagnosis is essential for timely implementation of disease control measures such as quarantine, vaccination, and enhanced farm biosecurity.

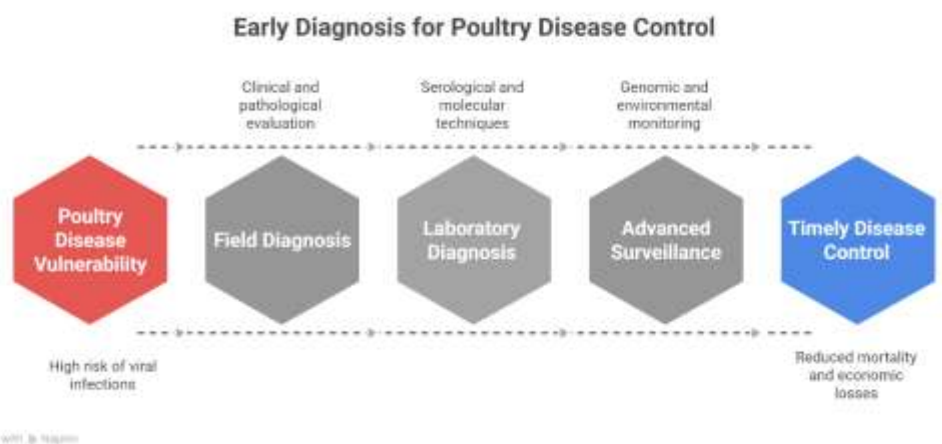
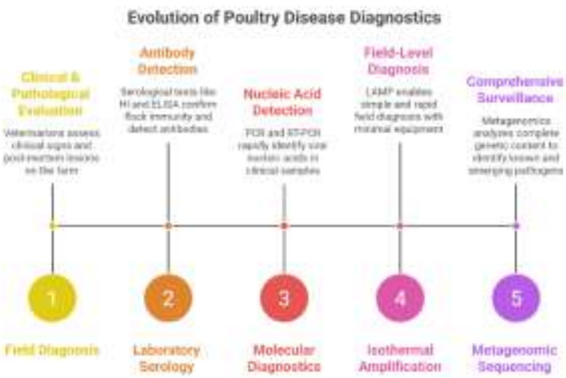


Table 1. Comparison of Major Diagnostic Methods for Poultry Viral Diseases

Diagnostic Method	Target Detected	Time Required	Advantages	Limitations
Clinical & Post-mortem examination	Lesions	Immediate	Low cost, easy	Low specificity
HI test	Antibodies	4–6 hours	Standard method for NDV/AIV	Cannot detect early infection
ELISA	Antibodies	3–5 hours	High throughput	Detects exposure rather than infection
RT-PCR	Viral genome	2–3 hours	Highly sensitive	Requires laboratory equipment
LAMP	Viral genome	<1 hour	Rapid, field applicable	Limited multiplex capability
Next-generation sequencing	Complete viral genome	24–48 hours	Detects emerging variants	Expensive

Among the most important viral diseases affecting poultry are Newcastle disease (ND), avian influenza (AI), infectious bursal disease (IBD), infectious bronchitis (IB), and Marek's disease. These diseases can spread rapidly within flocks and often result in high mortality, severe production losses, reduced egg production, poor growth performance, and increased veterinary costs. Consequently, early and accurate diagnosis becomes essential for implementing timely control measures such as quarantine, vaccination, treatment of secondary infections, and strengthening farm biosecurity. To effectively manage these diseases, modern poultry diagnostics are broadly categorized into three levels. The first level involves field-based clinical and pathological diagnosis, where veterinarians evaluate clinical signs and post-mortem lesions. The second level includes laboratory-based serological and molecular diagnostic techniques that confirm the presence of specific pathogens. The third level consists of advanced genomic and environmental surveillance technologies that enable comprehensive monitoring of emerging pathogens and disease dynamics within poultry production systems.

Modern poultry diagnostics encompass a range of serological, molecular, and advanced genomic approaches. Serological tests such as haemagglutination inhibition (HI) and enzyme-linked immunosorbent assay (ELISA) are widely used for monitoring flock immunity and detecting antibodies against major poultry viruses including Newcastle disease virus, avian influenza virus, infectious bursal disease virus, and infectious bronchitis virus. Molecular diagnostic techniques, particularly polymerase chain reaction (PCR) and reverse transcription PCR (RT-PCR), enable rapid and highly sensitive detection of viral nucleic acids directly from clinical samples, while real-time PCR allows quantification of viral load for epidemiological investigations. Rapid isothermal techniques such as loop-mediated isothermal amplification (LAMP) further facilitate field-level diagnosis due to their simplicity and minimal equipment requirements. More recently, metagenomic sequencing has emerged as a powerful diagnostic tool capable of identifying both known and emerging pathogens by analyzing the complete genetic content of clinical or environmental samples, thereby improving surveillance of the poultry virome and strengthening disease monitoring systems.



The Basic Tier: Conventional Diagnostic Methods

1. Clinical and Pathomorphological Evaluation

The earliest stage of diagnosis involves identifying pathognomonic clinical signs. For example, the torticollis and respiratory distress associated with Velogenic Viscerotropic Newcastle Disease (VVND) often provide the first diagnostic lead.

- **Post-Mortem (PM) Examination**: Gross lesions remain a fundamental, low-cost diagnostic tool.
- **Pathological Markers**: Hemorrhages in the proventriculus or cecal tonsils are classic markers for NDV, while a swollen, edematous Bursa of Fabricius characterizes IBDV.
- **Limitations**: Relying solely on gross pathology is increasingly difficult due to "variant" strains that produce atypical or mild lesions, necessitating laboratory confirmation.

Table 2. Sample collection guidelines for major poultry viral diseases

Disease	Preferred Samples	Stage of Disease	Collection Method
Newcastle disease	Tracheal swabs, cloacal swabs, brain tissue	Early clinical stage	Sterile swabs placed in viral transport medium
Avian influenza	Oropharyngeal swabs, cloacal swabs	Early infection	Swabs stored in viral transport medium and kept chilled
Infectious bursal disease	Bursa of Fabricius	Acute stage	Tissue collected aseptically during necropsy
Infectious bronchitis	Tracheal swabs, kidney tissue	Respiratory phase	Sterile swabs placed in transport medium
Marek's disease	Feather follicles, spleen	Chronic stage	Feather pulp or organ tissue collected aseptically

2. Serological Diagnostics

Serology remains the "workhorse" of poultry diagnostics, primarily used for flock health monitoring and vaccine titer evaluation.

- **Haemagglutination Inhibition (HI)**: Specifically used for haemagglutinating viruses like NDV and AIV. It is cost-effective and remains a standard in many Indian diagnostic labs.
- **ELISA (Enzyme-Linked Immunosorbent Assay)**: Widely utilized for its high throughput and ability to satisfy the protein-specific diagnostic demands of large-scale poultry operations.

The Intermediate Tier: Molecular Bench-side Tools

3. PCR and RT-PCR Technology

The development of the Polymerase Chain Reaction (PCR) transitioned diagnostics from detecting "responses" (antibodies) to detecting the "pathogen genome" (DNA/RNA).

- **Real-Time PCR (qPCR)**: Unlike conventional PCR, qPCR allows for the quantification of the viral load within a sample.
- **RT-PCR for RNA Viruses**: Since most major poultry threats are RNA viruses, Reverse Transcription PCR is essential to convert viral RNA into cDNA for amplification.

4. Loop-mediated Isothermal Amplification (LAMP)

LAMP has emerged as a bridge between the field and the laboratory. It eliminates the need for expensive thermal cyclers, as the reaction occurs at a constant temperature

Field Utility: Results are interpreted via a visual color change, allowing for rapid decision-making in remote farming clusters without advanced lab infrastructure.

Novel Content: The "Digital Twin" and AI-Driven Predictive Diagnostics

In 2026, a revolutionary diagnostic frontier has emerged: the integration of **Real-time Bio-Sensing with Digital Twin Technology**. Instead of waiting for clinical signs, poultry sheds are now equipped with acoustic and infrared sensors that monitor the "flock's signature." Any deviation in vocalization patterns or thermal distribution is processed by Artificial Intelligence (AI) to predict viral shedding up to 48 hours before physical symptoms appear. When this digital alert is triggered, in-situ nanopore sequencing is automatically activated to identify the specific viral strain. This "Zero-Lag" diagnostic model moves beyond detection into the realm of **Predictive Biosecurity**, allowing for targeted ring-vaccination and localized containment that can prevent a single-shed infection from becoming a regional epidemic.

The Advanced Tier: Next-Generation Frontiers

5. Metagenomic Surveillance

Metagenomics represents a "paradigm shift" where all genetic material in a sample is sequenced simultaneously.

- **Discovery of Variants**: This is critical for detecting "silent" mutations in viruses like Infectious Bronchitis (IBV), where minor genetic shifts can lead to vaccine failure.
- **Coinfection Analysis**: It provides a holistic view of the "virome," identifying secondary viral or bacterial invaders that exacerbate mortality.

6. Environmental DNA (eDNA) and Air Sampling

A significant advancement is the use of non-invasive environmental sampling.

- **Process**: High-volume air samplers or dust swabs from exhaust fans are analyzed via molecular tools.
- **Benefit**: This captures the viral profile of the entire shed without the stress and biosecurity risks associated with handling individual birds.

Key Messages for Poultry Farmers

1. Early reporting saves flocks

Report unusual mortality, respiratory signs, or sudden drop in egg production immediately to a veterinarian.

2. Laboratory diagnosis is essential

Clinical signs alone cannot confirm viral diseases. Laboratory testing helps identify the exact pathogen.

3. Maintain strict biosecurity

Limit visitor entry, disinfect equipment, and isolate new birds before introducing them into the flock.

4. Follow proper vaccination schedules

Vaccination is the most effective preventive measure against major poultry viral diseases.

5. Monitor flock health regularly

Observe birds daily for behavioral changes, feed intake, and egg production to detect disease early.

Conclusion

The future of poultry health in India depends on a "tiered" diagnostic approach. While basic clinical and serological methods provide the foundation for routine monitoring, the integration of molecular tools like LAMP and qPCR is necessary for rapid outbreak control. Advanced metagenomic surveillance and AI-driven predictive models serve as a "lookout" for emerging threats, ensuring that vaccine strategies remain relevant against evolving viral strains. For the veterinary professional, mastering this spectrum from the pen to the pipette is the key to securing the industry's future.

References

- Alexander, D.J. Newcastle disease and other avian paramyxoviruses. *Rev. Sci. Tech.* 2000;19(2):443-462.
- El-Tholoth, M., Bau, H.H. Molecular detection of respiratory tract viruses in chickens using LAMP technology. *Viruses.* 2024 Aug;16(8):1248.
- Kim, H.R., Kim, H.S., Kim, J.Y., Kwon, Y.K. Development of RT-LAMP assays for rapid detection of virulent Newcastle disease virus. *Int. J. Mol. Sci.* 2023;24(18):13847.
- Mihiretu, A. et al. Development of loop-mediated isothermal amplification assay for rapid diagnosis of Newcastle disease virus. *Vet. Med. Res. Rep.* 2025.
- OIE. *Manual of Diagnostic Tests and Vaccines for Terrestrial Animals.* Paris: World Organisation for Animal Health; 2022.
- Rahman, A.U. et al. Seroprevalence of Newcastle disease and avian influenza in poultry populations. *Vet. Ital.* 2023;59:245-253.
- Wei, J. et al. Next-generation sequencing reveals viral diversity in poultry markets. *Vet. Microbiol.* 2024;110136.

Just Agriculture Multidisciplinary *e- newsletter*

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Kumar Raj

Department of Agronomy, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj 211007, Uttar Pradesh, India

Rajesh Singh

Department of Agronomy, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj 211007, Uttar Pradesh, India

Akankhya Pradhan

Department of Agronomy, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj 211007, Uttar Pradesh, India

ARTICLE ID: 14

Sustainable Soil Health Management in India: Integrating Artificial Intelligence and Agricultural Waste Recycling for Climate-Smart Agriculture

Abstract

Context: Soil degradation, declining soil organic carbon, and inefficient management of agricultural residues threaten the sustainability of Indian agriculture. Excessive dependence on chemical fertilizers and open burning of crop residues contribute to nutrient imbalance, environmental pollution, and greenhouse gas emissions.

Objective: This study evaluates the potential of integrating sustainable soil management practices with artificial intelligence (AI) technologies and agricultural waste recycling to improve soil fertility, nutrient-use efficiency, and agricultural sustainability in India.

Methods: The study synthesizes recent scientific literature and policy reports on soil health management, precision agriculture, and biomass recycling. Emphasis is placed on composting, vermicomposting, and biochar production as strategies for enhancing soil organic carbon and nutrient cycling, along with AI-based tools for soil monitoring, pest detection, and precision nutrient management.

Results and conclusions: The integration of organic waste recycling with AI-enabled precision agriculture can substantially improve soil physical, chemical, and biological properties. Organic amendments increase soil organic matter and microbial activity, while AI-driven decision-support systems enhance fertilizer-use efficiency and enable real-time soil monitoring. These approaches collectively reduce nutrient losses, mitigate greenhouse gas emissions, and improve crop productivity.

Significance: Combining soil restoration strategies with digital agriculture technologies provides a promising pathway for sustainable intensification of Indian agriculture. Strengthening digital infrastructure, soil monitoring systems, and farmer capacity building will be essential to ensure large-scale adoption and long-term agricultural resilience.

Keywords: Soil health; Artificial intelligence in agriculture; Agricultural waste recycling; Soil organic carbon; Precision agriculture; Sustainable farming system

1. Introduction

Indian agriculture is undergoing a critical transition as soil degradation, widening yield gaps, and inefficient biomass management increasingly threaten long-term sustainability. Declining soil organic carbon, nutrient imbalances, excessive dependence on chemical fertilizers, and continuous intensive cultivation have weakened soil productivity across large parts of the country. Nearly one-third of India's land area shows signs of degradation, while many soils remain deficient in essential nutrients, reducing crop productivity and increasing production costs. At the same time, Indian agriculture generates large quantities of crop residues, livestock waste, and agro-industrial by-products.

Much of this biomass remains underutilized or is disposed of through open burning, contributing to greenhouse gas emissions and environmental pollution. Efficient recycling of these materials can restore soil organic matter, enhance nutrient cycling, and reduce dependence on chemical fertilizers.

Recent advances in digital agriculture and artificial intelligence provide new opportunities to address these challenges through precision nutrient management, soil monitoring, pest surveillance, and climate-informed decision support. Integrating soil health restoration, AI-enabled precision agriculture, and circular biomass management represents a promising pathway toward resilient and climate-smart agricultural systems in India.

1. Warning Signs of Soil Degradation

Data from the Soil Health Card Scheme indicate serious nutrient imbalances in Indian soils. Approximately 64% of soil samples are low in nitrogen, while nearly 48.5% are deficient in organic carbon. Furthermore, the national fertilizer consumption ratio of N:P:K (8:2.7:1) deviates significantly from the recommended ratio of 4:2:1.

Satellite assessments by national agencies suggest that about 29–30% of India's land area is affected by degradation or desertification. The major drivers responsible for soil degradation in India are summarized in **Table 1**.

Table 1. Major Causes of Soil Degradation in India

Cause	Percentage / Extent	Source
Soil erosion	~30% degraded land	ICAR
Nutrient depletion	25–40% soils deficient	CSE
Excess fertilizer use	10–15% cultivated area	ICAR
Monocropping	~20%	FAO
Loss of organic residues	~15%	NITI Aayog

2. Soil Health Crisis in India

Soil health is fundamental to agricultural productivity and food security. However, declining soil organic matter, nutrient depletion, and imbalanced fertilizer application are increasingly reducing soil fertility and crop productivity.

Large quantities of organic residues generated annually contain valuable nutrients and organic carbon. Recycling these materials through composting and biological processes can significantly improve soil structure, microbial activity, and nutrient availability. The major factors affecting soil health in India are summarized in **Table 2**.

Table 2. Major Factors Affecting Soil Health in India

Factor	Impact	Source
Nutrient depletion	~35% soils deficient	ICAR
Low organic matter	SOC <0.5% in many soils	CSE
Imbalanced fertilization	Micronutrient deficiencies	NITI Aayog
Intensive cultivation	Soil degradation	ICAR
Poor residue management	Organic carbon loss	CSE

3. Yield Gap and Climate Risks

India continues to experience substantial differences between potential and actual crop yields. These yield gaps arise due to limitations in soil fertility, inefficient fertilizer management, pest pressures, and climate variability. Climate change further intensifies these challenges by increasing temperature extremes, irregular rainfall patterns, drought frequency, and pest outbreaks. Key contributors to yield gaps in Indian agriculture are presented in Table 3.

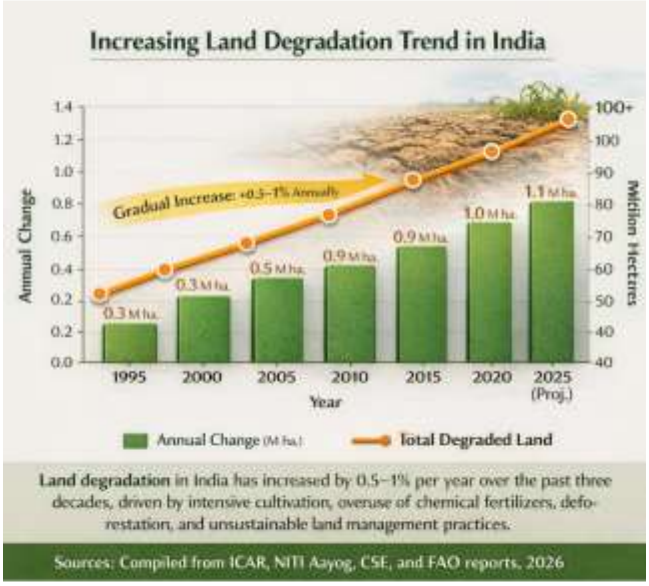
Table 3. Factors Contributing to Yield Gaps

Factor	Contribution (%)
Soil fertility constraints	30
Inefficient fertilizer use	20
Pest and diseases	15
Small landholdings	15
Climate variability	20

5. Artificial Intelligence in Agriculture

Artificial intelligence is becoming an important driver of agricultural modernization. AI-based digital agriculture systems provide data-driven decision support that improves input efficiency, productivity, and environmental sustainability. AI technologies are used to analyze soil data, weather patterns, crop health, and pest outbreaks. These systems enable precise nutrient recommendations, automated irrigation scheduling, and real-time monitoring of crop conditions. The workflow of AI-based crop monitoring systems is illustrated in **Fig. 1**.

Fig. 1. AI-based crop monitoring and pest detection workflow



The current status of AI adoption and barriers in Indian agriculture is summarized in **Table 4**.

Table 4. AI Adoption in Indian Agriculture

Indicator	Extent
Farmers using digital platforms	10–15%
Rural internet coverage	~40%
Post-harvest loss reduction	5–10%
Cost barriers	Affect ~60% farmers
Data availability gaps	~50% districts

6. Precision Soil Monitoring

Precision soil monitoring integrates satellite observations, sensors, and machine-learning models to generate high-resolution information on soil moisture, nutrient status, and organic carbon dynamics. These technologies enable site-specific nutrient management and improved fertilizer-use efficiency.

The conceptual framework of precision soil monitoring systems integrating digital data and soil sensors is shown in **Fig. 2**.

Fig. 2. Precision soil monitoring model

7. AI-Based Pest Detection Systems

AI-enabled pest monitoring systems combine smartphone imaging, drones, and machine learning algorithms to detect pest infestations at early stages. These systems compare crop images with trained datasets to identify pest species and generate advisory recommendations.

The operational structure of AI-enabled pest detection and early warning systems is illustrated in **Fig. 3**.

Fig. 3. AI-based pest detection and early warning system

8. Agricultural Waste Generation in India

India generates enormous quantities of agricultural residues each year. Estimates indicate that more than 700 million tonnes of crop residues and over 600 million tonnes of animal waste are produced annually. These materials contain significant amounts of nitrogen, phosphorus, and potassium that can supplement chemical fertilizers.

The scale of agricultural waste generation and nutrient potential is presented in **Table 5**.

Table 5. Agricultural Waste Generation in India

Waste Type	Quantity (Mt/year)
Crop residues	762.8
Animal waste	667.7
Unused residues	178

9. Sustainable Agricultural Waste Management

Sustainable waste management practices such as composting, vermicomposting, anaerobic digestion, and biochar production convert organic residues into valuable soil amendments. These practices enhance soil organic carbon, nutrient availability, and microbial activity while reducing greenhouse gas emissions.

10. Integrated Soil Health Restoration

Combining artificial intelligence with organic waste recycling offers a comprehensive strategy for sustainable soil management. Precision monitoring systems guide the efficient application of compost, biochar, and organic amendments according to soil conditions, improving nutrient cycling and reducing dependence on chemical fertilizers.

11. Environmental Benefits

The integration of sustainable soil management, AI technologies, and residue recycling significantly reduces greenhouse gas emissions, improves soil carbon storage, and enhances water-holding capacity. These practices contribute to climate resilience and environmental sustainability.

12. Policy Implications

Policy support is essential to promote sustainable residue management and digital agriculture. Incentives for composting, biochar production, and biogas generation can strengthen circular nutrient systems while reducing environmental pollution.

13. Future Research Directions

Future research should focus on integrated soil restoration strategies combining regenerative agriculture, organic amendments, and AI-driven precision farming. Long-term field studies are needed to evaluate the impacts of these interventions on soil carbon, nutrient dynamics, and crop productivity.

14. Conclusion

Soil degradation, nutrient imbalance, and inefficient biomass management present major challenges to agricultural sustainability in India. Recycling crop residues and livestock waste into compost, biochar, and digestate can restore soil fertility and increase organic carbon levels. When combined with AI-based soil monitoring and precision agriculture, these practices can improve nutrient-use efficiency, reduce environmental pollution, and enhance climate resilience. Integrating technology, sustainable soil management, and supportive policies offers a promising pathway toward productive, climate-smart, and environmentally sustainable agricultural systems in India.

References

- Centre for Science and Environment (2025) *Sustainable food systems: an agenda for climate-risked times.* Centre for Science and Environment, New Delhi.
- Centre for Science and Environment (2026a) *Soil health and crop residue management in India.* Centre for Science and Environment, New Delhi.
- Centre for Science and Environment (2026b) *Soil health, organic matter, and crop residue management.* Centre for Science and Environment, New Delhi.
- Centre for Science and Environment (2026c) *Crop productivity and pest management in India.* Centre for Science and Environment, New Delhi.
- Centre for Science and Environment (2026d) *Technology adoption in smallholder farming systems in India.* Centre for Science and Environment, New Delhi.
- Food and Agriculture Organization (2025a) *Global soil resources report.* FAO, Rome.
- Food and Agriculture Organization (2025b) *The state of food and agriculture 2025.* FAO, Rome.
- Food and Agriculture Organization (2026a) *Global land degradation assessment: India country report.* FAO, Rome.
- Food and Agriculture Organization (2026b) *Climate impacts on crop yields: India country report.* FAO, Rome.
- Indian Council of Agricultural Research (2025) *Soil health research report.* ICAR, New Delhi.
- Indian Council of Agricultural Research (2026a) *Status of land degradation in India: assessment and trends.* ICAR, New Delhi.
- Indian Council of Agricultural Research (2026b) *Status of soil health in India: assessment and trends.* ICAR, New Delhi.
- Indian Council of Agricultural Research (2026c) *Yield gap assessment in Indian agriculture: factors and trends.* ICAR, New Delhi.
- Indian Council of Agricultural Research (2026d) *Digital agriculture and AI adoption*

in India: opportunities and challenges. ICAR, New Delhi.

- Indian Council for Research on International Economic Relations (2026) *Healing soils in India: for better crop health and human nutrition.* ICRIER, New Delhi.
- Intergovernmental Panel on Climate Change (2024) *Climate change 2024: mitigation of climate change.* Cambridge University Press, Cambridge.
- Ministry of Agriculture & Farmers Welfare (2025) *Soil health card scheme dashboard.* Government of India, New Delhi.
- NASA, ISRO (2026) *NISAR mission: soil moisture monitoring and precision agriculture applications.* NASA–ISRO Joint Mission Report.
- Nature Research (2024) Alternative crop residue management practices to mitigate environmental impacts. *Scientific Reports* 14:65389. https://doi.org/10.1038/s41598-024-65389-0
- Nature Research (2025) Regenerative agriculture and soil organic carbon sequestration: meta-analysis of long-term field studies. *Scientific Reports* 15:12149. https://doi.org/10.1038/s41598-025-12149-0
- NITI Aayog (2026a) *Agriculture and land use report: land degradation trends and soil health.* Government of India, New Delhi.
- NITI Aayog (2026b) *Agriculture and soil management report.* Government of India, New Delhi.
- NITI Aayog (2026c) *Agricultural performance report: productivity and soil management.* Government of India, New Delhi.
- NITI Aayog (2026d) *AI and digital technologies in Indian agriculture: status report.* Government of India, New Delhi.
- Singh A, Sharma R, Kumar P (2025) Valorization of paddy straw through fermented organic manure: a circular economy approach for low-carbon agriculture. *Frontiers in Sustainable Food Systems* 9:1702102. https://doi.org/10.3389/fsufs.2025.1702102
- Singh SV, Chaturvedi S, Dhyani VC, Datta D (2019) Biochar: an eco-friendly residue management approach. *Indian Farming* 69(6):15–22.
- Telecom Regulatory Authority of India (2026) *Rural internet connectivity and digital infrastructure report.* TRAI, New Delhi.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

M. Nirmitha

[1]Ph. D. Scholar, College of Agriculture, Rajendranagar, PJTAU – 500030

K. Bhavitha

Teaching Associate, Agricultural College, Jagtial, PJTAU - 505529

K. Sravani

Teaching Associate, Agricultural College, Jagtial, PJTAU - 505529

ARTICLE ID: 15

Micronutrients as Drivers of Soil Health and Climate-Resilient Agriculture in India

Introduction

Healthy soil is the basis of productive agriculture. While nitrogen, phosphorus, and potassium dominate fertilizer recommendations, the importance of micronutrients is often overlooked. Crops require small amounts of elements such as zinc, iron, boron, manganese, copper, and molybdenum to regulate essential processes including chlorophyll formation, enzyme activity, flowering, grain filling, and resistance to stress.

Across many regions of India, intensive cropping, repeated irrigation, heavy dependence on NPK fertilizers, and reduced application of organic manures have gradually depleted native micronutrient reserves. Consequently, crops may appear stunted, show poor flowering, or yield less even when macronutrients are adequately supplied. Balanced micronutrient management is therefore critical for sustaining crop productivity, soil health, and produce quality.

Classification of Micronutrients

An element is considered essential if its absence prevents the plant from completing its life cycle and if it is directly involved in plant metabolism. The eight essential micronutrients are Iron (Fe), Zinc (Zn), Manganese (Mn), Copper (Cu), Boron (B), Molybdenum (Mo), Chlorine (Cl) and Nickel (Ni).

Status of Micronutrients in Indian Soils

Large-scale soil testing across India shows that micronutrient deficiencies are widespread and increasing. Zinc deficiency is the most severe affecting almost half of the agricultural soils in India and is accompanied by deficiency of boron (about one-third of the soils), iron, and to a lesser extent manganese and copper.

- **Zinc**: Common in Indo-Gangetic plains, red and lateritic soils, and intensively irrigated systems.
- **Boron**: Widespread in Eastern India and light-textured soils.
- **Iron**: Predominantly in calcareous and alkaline soils of northwestern states.

Rice–wheat systems, vegetable belts, sugarcane fields, and horticultural crops are especially vulnerable due to high nutrient removal and irrigation acceleration. Continuous cropping without micronutrient replenishment has led to nutrient mining, leading to hidden deficiencies that reduce yield and quality of crops even when NPK levels are adequate.

Factors Responsible for Micronutrient Deficiency

1. Imbalanced Fertilizer Use - Excessive NPK application without micronutrient supplementation creates nutrient antagonism, particularly phosphorus-induced zinc deficiency.

2. Intensive Cropping - High-yielding varieties extract greater quantities of micronutrients each season.

3. Declining Organic Matter - Reduced use of farmyard manure and crop residues lowers soil organic carbon, which normally helps retain micronutrients in plant-available forms.

4. Soil Chemical Constraints - High pH and calcareous soils reduce zinc and iron availability while sandy soils are prone to boron and zinc leaching.

5. Limited Soil Testing and Awareness - Deficiency symptoms are often mistaken for disease or water stress, delaying corrective measures.

Role of Micronutrients in Crop Productivity, Quality and Soil Health

- Zinc enhances root growth, enzyme activity, and hormone regulation.
- Iron supports chlorophyll formation and photosynthesis.
- Boron ensures proper pollen viability and seed development.
- Manganese and Copper regulate carbohydrate metabolism and structural strength.
- Molybdenum improves nitrogen fixation and protein synthesis in legumes.

Beyond productivity, micronutrients improve food quality and nutritional security by increasing zinc and iron concentration supporting biofortification and helping address widespread micronutrient deficiencies in human populations. They also act as cofactors for soil microorganisms involved in organic matter decomposition and nutrient cycling. Balanced management improves microbial activity, soil aggregation and water holding capacity.

Micronutrients in Stress Tolerance and Climate-Resilient Agriculture

Micronutrients strengthen plant tolerance to **drought, heat, salinity and disease.** Zinc improves root growth, membrane integrity and stomatal regulation, enabling plants to withstand moisture stress. Iron and manganese stabilize chloroplast structure and protect the photosynthetic system under heat and light stress. Copper and zinc activate antioxidant enzymes that detoxify harmful reactive oxygen species produced during drought and temperature extremes. Boron strengthens cell walls and improves pollen viability under heat stress, while molybdenum enhances nitrogen fixation even under sub-optimal conditions. With climate change increasing the frequency of abiotic stresses, balanced micronutrient nutrition has become a key component of **climate-smart agriculture** in India.

Strategies for Effective Micronutrient Management

Micronutrient deficiencies can be corrected through soil application of zinc sulphate, borax, ferrous sulphate, and copper sulphate. Foliar sprays provide rapid correction during critical growth stages, while seed treatment and fertigation enhance efficiency.

Integrated Micronutrient **Management (IMM)** combines chemical fertilizers with **organic manures, compost, crop residues and biofertilizers to offer a sustainable approach.** Organic matter improves micronutrient availability by chelation and reduced fixation while biofertilizers such as zinc-solubilizing bacteria increase nutrient uptake. IMM ensures sustainable productivity, soil health and cost-effectiveness in Indian farming systems.

Constraints in Adoption

Despite their importance, micronutrients are not widely used by many farmers due to **lack of awareness**, inadequate soil testing facilities, limited availability of micronutrient fertilizers in rural markets and the perception that NPK fertilizers alone are sufficient. The initial cost of micronutrient fertilizers also discourages small and marginal farmers. In addition, deficiency symptoms are often mistaken for disease or water stress, leading to improper diagnosis and management.

Conclusion

Micronutrients are small in quantity but immense in importance. Their balanced management is essential for improving crop yields, soil health, nutritional quality and climate resilience of Indian agriculture. Addressing micronutrient deficiencies is not only an agronomic necessity but also a national priority for achieving food, nutritional and environmental security. Attention to these “small nutrients” can result in big gains in yield, quality, and farm income.

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Krishna Chaitanya Tirunagaru

Assistant Professor - Agricultural Entomology, SVKM's College of Agriculture – Tardi, (Affiliated to Mahatma Phule Krishi Vidyapeeth, Rahuri), Shirpur – 425421, Dhule, Maharashtra, India

ARTICLE ID: 16

When neem forgets its season (Unseasonal mid-monsoon flowering of neem (*Azadirachta indica*) observed in Shirpur, Maharashtra)

Abstract

Neem (Azadirachta indica) is one of India's most familiar trees, found in farmyards, roadsides and temple courtyards all across the country. Its flowering is normally a spring affair, occurring from March to April. However, since 2022, I have observing neem trees behind my rented house in Shirpur taluka, Dhule district, Maharashtra, producing flowers during middle of the July to August, the heart of the monsoon season. This unusual flowering has repeated every year from 2022 to 2025. The present article documents these field observations, examines the scientific reasons behind such off-season behaviour, and puts forward simple monitoring steps and working hypotheses for future study. The most likely explanations are: shifts in local climate (warming and erratic rainfall), stress-triggered flowering (drought or sudden changes in water availability), the combined effect of drought and unusual temperature cues, and local micro-environmental factors such as soil disturbance or pruning.

Keywords: *Azadirachta indica*, unseasonal flowering, phenology, drought stress, climate change.

Introduction

Neem (*Azadirachta indica*) needs no introduction to any Indian. This hardy, fast growing tree is a constant presence in our villages and cities alike, valued for its shade, its medicinal properties, and its well-known bitter leaves and fruits. In most parts of India, neem flowers reliably in late winter and early spring, typically from March to April. Its flowering is so predictable that farmers and villagers have long used it as a seasonal marker.

Fig. 1: Neem (*Azadirachta indica*) trees in full flower during monsoon season, July 2025

The timing of a plant's life events leafing, flowering, fruiting and seed dispersal is called its phenology. For most trees, phenology is tightly controlled by seasonal cues: temperature, day length (photoperiod) and water availability. When these cues change, whether due to long term climate change or local disturbances, the plant's biological clock can go out of sync. Across the world, scientists are documenting such shifts in flowering times in response to climate variability and environmental stress. This short article presents a systematic field observation of neem trees flowering during the monsoon months (mid-July to August) in Shirpur, Dhule district, over four consecutive years (2022–2025) (Fig. 1). It then explores scientific explanations available in published literature that could account for this unusual behaviour.

Results and Discussion:

1. Climate variability and warming shifting phenology:

One of the most important and well-documented reasons for off-season flowering in trees is warming temperature and changing rainfall patterns. When winters become milder and summers stretch longer, many plants receive altered temperature signals that their flowering systems interpret differently from what they would have experienced even a few decades ago.

Maharashtra has recorded temperatures consistently above its long period averages in recent years. Such regional warming can disrupt the seasonal temperature patterns that trees depend upon to time their flowering. A 2024 study by Austin *et al*. published in New Phytologist demonstrated that climate change is increasing flowering duration in multiple plant species, causing a rearrangement of when species flower together. This kind of phenological mismatch where plants flower at unexpected times is being increasingly reported in both crop plants and wild trees across tropical Asia.

For neem trees in Shirpur, located in the warm, semi-arid Dhule district, even small shifts in temperature or rainfall timing could be enough to confuse the tree's internal calendar and push it into flowering during an unusual season.

2. Stress-induced flowering (drought or water stress)

Plants are not passive organisms, they respond actively to environmental hardship. One well-known response is stress induced flowering, where a plant accelerates its reproductive cycle when it senses that survival conditions have become difficult. This is sometimes called "drought escape" the plant essentially tries to set seed before it perishes.

Water stress, particularly a sudden drop in soil moisture is a powerful trigger for this response. When a tree experiences drought followed by sudden rewetting (such as the arrival of monsoon rains after a dry spell), its hormonal balance can shift dramatically. Plant hormones, especially abscisic acid (ABA) and its interactions with gibberellins and the florigen pathway (the molecular signal that travels from leaves to the growing tip to initiate flowering), are known to mediate this stress response. In the Dhule district, which is characterised by semi-arid conditions and erratic monsoon onset, neem trees routinely experience periods of drought followed by the sudden abundance of monsoon rainfall. This kind of stop-start water availability is precisely the stress that, according to a comprehensive review by Kiyotoshi Takeno (2016) in the Journal of Experimental Botany, can trigger off-season flowering in trees and other plants.

3. Interaction of drought and temperature / unusual seasonal cues

The story becomes more interesting when we consider that it is often the combination of two or more unusual cues not a single factor that pushes a tree into flowering out of season. Many tropical and subtropical fruit trees are known to flower when they experience a specific sequence of environmental signals: a period of drought, followed by a cooling event or the arrival of rainfall after a prolonged dry spell.

A well, studied example is litchi (*Litchi chinensis*), another subtropical fruit tree grown widely in India. Research by Shen et al. (2016) using genome-wide transcriptome analysis showed that drought and low temperature acting together significantly altered gene expression in ways that promoted floral initiation, effects that neither drought nor cold alone produced as strongly. Similar combined effects may be operating in the neem trees of Shirpur during the pre-monsoon and early monsoon period.

In the weeks before mid-monsoon in the Dhule region, there are sometimes unusual temperature dips at the onset of the rainy season, or temporary dry spells within the monsoon itself. If neem trees had already been under water stress and then experienced such a combination of cues, it could plausibly have triggered the floral response observed. Systematic recording of daily weather patterns alongside future flowering events will be essential to test this hypothesis.

4. Local micro-environmental and management factors

Not all causes of off-season flowering need to be large-scale. Sometimes, very local changes in a tree's immediate environment are sufficient to alter its phenology. These include root damage during construction or road widening, soil disturbance near the base of the tree, application of fertilisers or changes in nearby irrigation, pruning of branches, removal of shade trees, or changes in land use close by. Urban and peri-urban trees are particularly susceptible to microclimate effects: nearby paved surfaces retain heat, reflected sunlight raises canopy temperature, limited soil volume restricts water uptake, and restricted air circulation raises humidity around the canopy. Any of these can alter the temperature and moisture conditions experienced by a tree's roots and crown — effectively creating a different microclimate from the surrounding landscape.

Research by Tewari *et al*. (2016) on *Rhododendron arboreum* in the central Himalayas showed that tree water potential, the internal water status of the tree plays a direct and measurable role in inducing flowering. When water potential dropped to stress levels, flowering was initiated earlier and more intensely than in well-watered trees. Similar mechanisms may operate in neem. Observing whether one or several trees are affected, and mapping their proximity to build structures, paved areas or disturbed soil, can help distinguish local from landscape level drivers.

Way Forward: What Should Be Observed Next?

The four years observation in Shirpur is valuable precisely because it is repeated, this is not a one off curiosity but a recurring pattern that demands scientific explanation. To move from observation to understanding, some simple but systematic follow up measurements are recommended.

Recording daily maximum and minimum temperatures and rainfall at the observation site, particularly in the six to eight weeks before flowering is observed each year, will help identify which weather patterns consistently precede the off season event.

Monitoring soil moisture levels near the trees during the pre-flowering period, even simple, low-cost soil moisture meters available at agricultural input shops can provide useful data for this purpose. Mapping the site to note the proximity of affected trees to roads, paved surfaces, buildings, construction activity, and nearby sources of irrigation or drainage channels.

Checking whether other neem trees in Shirpur and neighbouring areas also show monsoon flowering. Wider occurrence would point to a climatic or landscape level driver; localised occurrence would suggest micro environmental cause’s specific to those trees. Such observations, even without expensive equipment, can form the basis for a more formal study or a citizen science initiative involving agriculture students, farmers and forest department staff.

References

- Austin, M.W., Smith, A.B., Olsen, K.M., Hoch, P.C., Krakos, K.N., Schmocker, S.P. and Miller-Struttmann, N.E. (2024). Climate change increases flowering duration, driving phenological reassembly and elevated co-flowering richness. New Phytologist, 243: 2486–2500. doi: 10.1111/nph.19994
- Takeno, K. (2016). Stress-induced flowering: the third category of flowering response. Journal of Experimental Botany, 67(17): 4925–4934. doi: 10.1093/jxb/erw272
- Shen, J., Xiao, Q., Qiu, H., Chen, C. and Chen, H. (2016). Integrative effect of drought and low temperature on litchi (*Litchi chinensis* Sonn.) floral initiation revealed by dynamic genome-wide transcriptome analysis. Scientific Reports, 6: 32005. doi: 10.1038/srep32005.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Anusha N M
Ravi Dupdal
Mahipal Choudhary
B Krishna Rao

ARTICLE ID: 17

Bridging the Oil Gap: The Potential of Oil Palm to Revolutionize India's Edible Oil Industry

Abstract:
Due to rising consumption and low productivity of traditional oilseed crops, India is experiencing a growing imbalance between domestic supply and edible oil demand. The potential of *Elaeis guineensis* as a revolutionary way to lessen reliance on imports and increase self-sufficiency is examined in this article. At the moment, palm oil accounts for the majority of India's edible oil imports. Oil palm is a very efficient crop since it provides a significantly higher oil production per hectare than traditional oilseeds like groundnut, mustard, and soybean. The study emphasizes oil palm's agronomic, economic, and productivity benefits, such as its long productive life and potential for intercropping. It also examines government programs, especially the National Mission on Edible Oils–Oil Palm (NMEO-OP), which seeks to increase crude palm oil production, increase planting area, and assist farmers with infrastructure and subsidies. Despite its potential, problems like price volatility and sustainability issues still exist. The study comes to the conclusion that oil palm may significantly contribute to closing India's edible oil gap and bolstering its agricultural economy with a balanced strategy that incorporates scientific cultivation, policy support, and environmental safeguards.

Introduction:

India, one of the fastest-growing economies in the world, confronts a subtle but crucial issue: the growing disparity between local production and edible oil demand. Although cooking oils are a necessary component of every Indian kitchen, the nation's demands are largely met by imports and is the largest importer of edible oils in the world. Palm oil accounts for over 56% of all imported edible oils, with soybean oil ranking in second at 27% and sunflower at 16%. The production of edible oil in the country has not been able to keep up with the rise in consumption, which has surpassed 25 million tonnes. In 2012–13, per capita consumption was 15.8 kg per person annually; today, it is approximately 19.00 kg. Indian agriculture is dominated by oilseed crops including groundnuts, mustard, and soybeans, although their oil yield per hectare is very poor.Policymakers are looking for high-yield alternatives because of this imbalance between supply and demand, and oil palm is the most viable choice. In this regard, oil palm production has become a game-changer, providing a route to independence while raising farmers' earnings.

Oil palm production in India

The oil palm (*Elaeis guinensis*) is a comparatively new crop in India that can provide the most vegetable oil per hectare. It is native to West Africa. It yields two different oils, palm oil and palm kernel oil, which are utilized in both industrial and culinary applications. The fleshy mesocarp of the fruit, which contains between 45 and 55 percent oil, is the source of palm oil. Lauric oils are derived from palm kernel oil, which is extracted from the oil palm kernel.

The three states that grow the most oil palm—Andhra Pradesh, Telangana, and Kerala—account for 98% of the total production. Large tracts of oil palm are also grown in Karnataka, Tamil Nadu, Odisha, Gujarat, and Mizoram. Oil palm plantation initiatives have recently been started in Arunachal Pradesh, Assam, Manipur, and Nagaland. After attaining the age of 8 to 9 years, oil palm can yield 20 to 25 MT of fresh fruit bunches (FFBs) per hectare with good planting materials, irrigation, and maintenance. Comparatively speaking, palm oil yields five times as much edible oil as other oilseeds.

Why Oil Palm is a Game Changer

Oil palm is often referred to as a "golden crop" because to its remarkable economic potential and productivity. It is one of the most effective producers of edible oil, producing about 10 times as much oil per hectare as conventional oilseed crops. Compared to crops like soybean, mustard, or groundnuts, oil palm produces an average of 4 tonnes of oil per hectare (Table 1). Its extended productive lifespan of roughly 25 to 30 years, which guarantees farmers a steady income for decades, is another significant benefit. Furthermore, the crop permits intercropping with vegetables, lentils, or other short-duration crops in the early years before the canopy fully develops, giving farmers additional revenue and improved land use.

Table 1:Comparative oil yields of different crops:

Crop	Scientific name	Oil yield/(tonnes/ ha/year)
Oil Palm	Elaeis guineensis	3.5 – 6.0
Coconut	Cocos nucifera	0.7 – 1.5
Groundnut	Arachis hypogae	0.4 – 0.6
Mustard/Rapeseed	Brassica juncea	0.5 – 0.8
Sunflower	Helianthus annuus	0.6 – 0.9
Soybean	Glycine max	0.3 – 0.5
Sesame	Sesamum indicum	0.2 – 0.4

Government Initiatives

The Indian government has been working hard to expand oil palm production. Through programs like the Technology Mission on Oilseed & Pulses (TMOP), Integrated Scheme on Oilseeds, Pulses, Oil Palm and Maize (ISOPOM), Oil Palm Area Expansion (OPAE), National Mission on Oilseeds and Oil Palm (NMOOP), and the National Food Security Mission (NFSM)–Oilseeds & Oil Palm, in 13 states—Andhra Pradesh, Telangana, Chhattisgarh, Karnataka, Odisha, Mizoram, Nagaland, Assam, Arunachal Pradesh, and Manipur—with funding patterns of 60:40 for general states and 90:10 in case of North-Eastern States and hill States.

The lack of a guaranteed price for FFBs for oil palm farmers and the unpredictability of FFB payment due to its connection to the landed CPO price, which is subject to significant fluctuations in payment, are the two main causes of India's slow oil palm development. The urgency of expanding the oil palm industry is of national importance and does not require undue stress given the rising domestic demand for edible oils, the startling shortage, and the expense to the exchequer from imports. Therefore, in order to meet the needs of the country, the National Mission on Edible Oils-Oil Palm (NMEO-OP) was established with the goal of improving the production of edible oilseeds and the availability of oils in the nation by utilizing the expansion of the Oil Palm area, boosting CPO production, and lowering the burden of edible oil imports.

NMEO-OP (National Mission on Edible Oils-Oil Palm)

The National Mission on Edible Oils-Oil Palm (NMEO-OP) launched in 2021 as a centrally sponsored program, seeks to boost domestic oil palm planting in India to 10 lakh hectares and increase Crude Palm Oil (CPO) production to 11.20 lakh tonnes by 2025–2026. By providing farmers with high-quality seedlings, fertiliser, and technology—particularly in the Northeastern states and the Andaman and Nicobar Islands—it aims to lessen reliance on imports.

The following is the goal set by NMEO-Oil Palm for the increase of oil palm areas by 2025–2026:

- To expand oil palm from 3.5 lakh hectares in 2019–20 to 10 lakh hectares by 2025–2026 (an additional 6.50 lakh ha). With a targeted FFB production of 66.00 lakh tonnes, the aim is 3.22 lakh hectares for general states and 3.28 lakh ha for North Eastern states.
- To raise crude palm oil production from 0.27 lakh tonnes in 2019–20 to 11.20 lakh tonnes in 2025–2026 and 28 lakh tonnes in 2028–2029.
- Raise consumer knowledge in order to sustain the 19.00 kg/person/year consumption level through 2025–2026.

Fig 1: Strategy to increase area and production of oil palm by NMEO-OP

Conclusion:

Oil palm presents an inviting pathway with its extraordinarily high yield and effective land use, which is necessary to address India's expanding edible oil need and significant reliance on imports. However, a well-rounded strategy that incorporates scientific farming, robust regulatory backing, farmer incentives, and environmental protections is necessary for its success in transforming the industry. Oil palm has the potential to significantly lower imports, increase farmer incomes, and help India become self-sufficient in edible oils while maintaining sustainable agricultural growth if it is cultivated sustainably.

References:

1. Government of India, Ministry of Agriculture & Farmers Welfare. (2021). *National Mission on Edible Oils – Oil Palm (NMEO-OP).*

2. NITI Aayog. (2024). *Pathways and strategy for accelerating growth in edible oils towards Atmanirbhar Bharat.* Government of India.

3. Mathur, R. K., Manorama, K., Kalyanababu, B., Ravichandran, G., Ramachandrudu, K., & Prasad, M. V. (2021). Innovations to make India self-reliant in edible oil production: the story of oil palm. In *Innovations in Agriculture for a Self-Reliant India*(pp. 83-102). CRC Press.

4. Valiyaveettil, R. R., Jha, G. K., & Kathayat, B. (2023). Pushing for self-sufficiency in edible oils in India in the aftermath of recent global events. *National Academy Science Letters*, *46*(6), 483-486.

5. Kalkoti, G. K. (2015). Attaining Self-sufficiency in Edible Oils: Need for Strategic Action Plan. *FIIB Business Review*, *4*(4), 21-29.

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

ARTICLE ID: 18

Organic Farming with Residue-Free Production: A Sustainable Approach for Safe and Healthy Food Systems

AUTHORS' DETAILS:

Satendra Kumar
Department of Agricultural Engineering and Technology, Affiliation- School of Engineering Technology, Nagaland University Add- Kohima Campus Nagaland, 797004

Abstract
Organic farming with residue-free production has gained global attention as a sustainable approach to ensuring food safety, environmental protection, and improved human health. Synthetic pesticides and fertilizers are frequently used extensively in conventional agriculture, which may leave hazardous residues in food and the environment. By utilizing natural inputs, ecological processes, and sustainable agricultural techniques, organic farming systems seek to reduce or eliminate such residues. In order to allay consumer worries about food safety, residue-free farming focuses on growing crops without leaving dangerous chemical residues on the finished product. The idea, tenets, methods, advantages, difficulties, and possibilities for organic farming for residue-free production are all covered in this article. It also emphasizes how this farming strategy may support sustainable food systems, safeguard ecosystems, and supply wholesome food to the world's expanding population.

1. Introduction

Millions of people around the world depend on agriculture for their livelihoods and food security. However, in order to boost crop output, modern agricultural techniques brought about by the Green Revolution mostly rely on synthetic fertilizers, pesticides, and herbicides. Although these technologies contributed to a rise in food production, they also brought up significant health and environmental issues. When consumed in excess, chemical pesticides used to manage pests and diseases may leave residues on agricultural products and endanger consumers (World Health Organization [WHO], 2022).

The need for safer and healthier food has grown as public awareness of environmental sustainability and food safety has grown. Consequently, residue-free agriculture and organic farming have become viable substitutes for traditional farming methods (Gamage et al., 2023). The use of artificial fertilizers, pesticides, and genetically engineered organisms is avoided in organic farming. In order to preserve soil fertility and crop productivity, it instead highlights natural methods including crop rotation, composting, biological pest control, and the application of organic manures (National Centre for Organic and Natural Farming, 2021). Producing agricultural products with minimal or no hazardous chemical residues is the main goal of residue-free farming. Residue-free farming guarantees that the finished crop satisfies safety requirements for human consumption, even though it may permit the limited use of safe inputs (Ananthi & Shree, 2024).

2. Concept of Organic Farming and Residue-Free Production

2.1 Organic Farming

The goal of organic farming is to maintain the health of humans, animals, plants, and soil. To sustain soil fertility and crop yield, it depends on natural inputs and ecological processes (National Centre for Organic and Natural Farming, 2021).

The key characteristics of organic farming include:

- Avoidance of synthetic fertilizers and pesticides
- Use of organic manures and compost
- Crop rotation and intercropping
- Biological pest control
- Conservation of biodiversity

Organic agriculture promotes long-term sustainability by maintaining ecological balance and improving soil health (Gamage et al., 2023).

2.2 Residue-Free Production

The term "residue-free farming" describes farming methods that guarantee crops are harvested free of dangerous pesticide residues. In this strategy, farmers employ safe pest control methods such integrated pest management (IPM), botanical pesticides, and biological control agents (Ananthi & Shree, 2024).

Food safety and consumer health are the main priorities of residue-free farming. Producing crops with pesticide residue levels below the maximum residual limits (MRLs) set by food safety authorities is the goal (WHO, 2022).

3. Principles of Organic Farming

The International Federation of Organic Agriculture Movements (IFOAM) established four guiding principles for organic farming. These guidelines aid in ensuring that farming methods continue to be socially and environmentally responsible.

3.1 Principle of Health

According to the health principle, organic farming should maintain and improve the health of the land, plants, animals, people, and the environment. Because it delivers nutrients, fosters microbial life, and enhances plant growth, healthy soil is the cornerstone of productive agriculture (Gamage et al., 2023).

Organic farming avoids synthetic chemicals that could taint food or damage soil ecosystems. Instead, it promotes the use of green manure, compost, and natural fertilizers to maintain soil fertility (National Centre for Organic and Natural Farming, 2021). Healthy soil supports beneficial bacteria that help recycle nutrients, break down organic debris, and prevent plant diseases. As a result, crops grown in organic systems often contain more nutrients and are better for human health (Vigar et al., 2019).

3.2 Principle of Ecology

Natural ecological cycles and systems are compatible with organic farming. Farmers use ecological methods that preserve biodiversity and environmental balance rather than depending on artificial inputs (Gamage et al., 2023). Crop rotation, intercropping, agroforestry, and organic residue recycling are examples of common ecological techniques. These methods assist beneficial insects and natural pollinators, lessen pest outbreaks, and preserve soil fertility.

3.3 Principle of Fairness

In agricultural production systems, the fairness concept fosters justice and equity. Fair connections between farmers, workers, consumers, and the environment are supported by organic agriculture. Organic farming encourages fair trade, ethical treatment of animals, and safe working conditions for agricultural workers (National Centre for Organic and Natural Farming, 2021).

3.4 Principle of Care

The duty to safeguard human health and the environment for both current and future generations is emphasized by the principle of care. Precautionary measures are used in organic farming to mitigate the dangers related to hazardous agricultural chemicals (Gamage et al., 2023). Organic farmers keep a close eye on their operations and use eco-friendly methods to reduce harm to the environment.

4. Techniques Used in Organic and Residue-Free Farming

Several agricultural techniques are used to achieve residue-free production and maintain soil fertility.

4.1 Crop Rotation

Growing various crops on the same plot of land in a predetermined order is known as crop rotation. This method prevents nutrient depletion, lowers pest infestations, and increases soil fertility (National Centre for Organic and Natural Farming, 2021).

Because they fix atmospheric nitrogen in the soil, leguminous crops like beans and peas are frequently used in crop rotation.

4.2 Organic Manures and Compost

Natural fertilizers made from plant and animal waste are called organic manures. Green manure, vermicompost, compost, and farmyard manure are a few examples.

According to Gamage et al. (2023), these organic compounds improve soil structure, boost microbial activity, and increase water-holding capacity.

4.3 Biological Pest Control

Microorganisms and natural predators are used in biological pest management. Aphids are managed by ladybird beetles, and insect pests are managed by microorganisms like Bacillus thuringiensis. This technique leaves no hazardous residues on crops and is safe for the environment (Ananthi & Shree, 2024).

4.4 Biofertilizers

Biofertilizers are living microorganisms that improve nutrient availability in soil. Examples include Rhizobium bacteria, Azotobacter, and mycorrhizal fungi. These microorganisms enhance plant growth and reduce dependence on chemical fertilizers (National Centre for Organic and Natural Farming, 2021).

4.5 Integrated Pest Management (IPM)

Integrated Pest Management combines biological, mechanical, and cultural methods to control pests with minimal chemical use.

IPM strategies include pest monitoring, resistant crop varieties, biological control agents, and mechanical traps (Ananthi & Shree, 2024).

4.6 Botanical Pesticides

Botanical pesticides are natural substances extracted from plants, such as neem oil, garlic extract, and chili spray.

These natural pesticides effectively control pests and decompose quickly in the environment, leaving minimal residues (Ananthi & Shree, 2024).

5. Benefits of Organic Farming with Residue-Free Production

5.1 Food Safety and Human Health

Residue-free farming reduces the presence of harmful pesticide residues in food, improving consumer safety (WHO, 2022).

Research has shown that organic foods often contain lower pesticide residues and higher antioxidant content compared to conventional foods (Vigar et al., 2019).

5.2 Environmental Protection

Organic farming reduces environmental pollution by eliminating synthetic agrochemicals. It protects soil, water resources, and wildlife habitats (Gamage et al., 2023).

Organic farming practices also help mitigate climate change by increasing soil carbon storage.

5.3 Soil Fertility Improvement

Organic farming enhances soil fertility through the addition of organic matter and the promotion of beneficial microorganisms (National Centre for Organic and Natural Farming, 2021).

Healthy soils improve crop productivity and long-term agricultural sustainability.

5.4 Biodiversity Conservation

Organic farms support greater biodiversity due to reduced chemical usage and diversified cropping systems (Gamage et al., 2023).

Pollinators such as bees and butterflies thrive in organic farming systems.

5.5 Economic Opportunities for Farmers

Organic and residue-free products often fetch premium prices in markets due to increased consumer demand for healthy food (Ananthi & Shree, 2024).

Farmers can also reduce production costs by minimizing expensive chemical inputs.

6. Challenges of Organic and Residue-Free Farming

6.1 Lower Yields During Transition

Farmers transitioning from conventional to organic farming may experience lower yields initially because soil ecosystems require time to recover (Gamage et al., 2023).

6.2 Pest and Disease Management

Managing pests without synthetic pesticides can be challenging and requires knowledge of biological and ecological control methods (Ananthi & Shree, 2024).

6.3 Certification and Regulatory Requirements

Organic certification involves strict guidelines, documentation, and inspections, which can be costly and time-consuming for small farmers (National Centre for Organic and Natural Farming, 2021).

6.4 Market Access

Limited infrastructure and consumer awareness may restrict market access for organic products in some regions (Ananthi & Shree, 2024).

6.5 Knowledge and Training Gaps

Specialized understanding of soil health, ecological pest control, and sustainable farming methods is necessary for organic farming. Extension services and training programs are unavailable to many farmers (Gamage et al., 2023).

7. Role of Organic Farming in Sustainable Food Systems

Organic farming contributes significantly to sustainable agriculture and global food security. Sustainable food systems aim to produce nutritious food while protecting environmental resources for future generations. Organic agriculture helps achieve sustainability by reducing chemical pollution, improving soil health, conserving biodiversity, and supporting rural livelihoods (Gamage et al., 2023).

8. Future Prospects

The future of organic farming and residue-free production is promising due to increasing consumer awareness and demand for healthy food. Technological advancements and supportive government policies can further promote the adoption of sustainable agricultural practices worldwide (National Centre for Organic and Natural Farming, 2021).

9. Conclusion

Organic farming with residue-free production provides a sustainable and environmentally responsible solution to many of the challenges associated with modern agricultural practices. Environmental deterioration, deteriorating soil health, and the presence of dangerous chemical residues in food products are all consequences of conventional farming's overuse of synthetic fertilizers and pesticides. By encouraging natural processes, ecological balance, and sustainable resource management, organic and residue-free agricultural techniques provide a safer option.

Organic farming increases soil fertility, preserves biodiversity, and reduces environmental pollution by using fewer synthetic chemicals and implementing techniques like crop rotation, applying organic manure, biological pest control, and integrated pest management. These methods improve the quality and safety of agricultural goods while also safeguarding natural ecosystems. As consumers become increasingly aware of the health risks associated with pesticide residues, the demand for organic and residue-free food is steadily increasing across the world.

However, there are a number of obstacles to overcome when switching to organic farming, such as lower yields in the early years, pest management issues, certification fees, and restricted market access. These issues can be resolved with stronger market infrastructure, more farmer training, and supporting government policies. In the end, residue-free organic farming offers a great deal of potential to advance sustainable agriculture, guarantee food safety, and safeguard human and environmental health.

References

1. Ananthi, T., & Shree, S. (2024). Organic farming for residue-free production. *Journal of Experimental Agriculture International*.
2. Gamage, A., Gangahagedara, R., Gamage, J., Jayasinghe, N., Kodikara, N., & Suraweera, P. (2023). Role of organic farming for achieving sustainability in agriculture. *Frontiers in Sustainable Food Systems*.
3. National Centre for Organic and Natural Farming. (2021). *Introduction to organic farming*. Government of India.
4. Vigar, V., Myers, S., Oliver, C., Arellano, J., Robinson, S., & Leifert, C. (2019). A systematic review of organic versus conventional food consumption. *Nutrients*, 12(1), 7.
5. World Health Organization. (2022). *Pesticide residues in food*. WHO.

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

ARTICLE ID: 19

Rust that Rescues: Eco-Friendly Control of Parthenium Weed in Tobacco Landscapes

AUTHORS' DETAILS:

Guru, P. N.
ICAR-National Institute for Research on Commercial Agriculture, Research Station, Hunsur-571105, Mysuru, Karnataka

Nanda, C.
ICAR-National Institute for Research on Commercial Agriculture, Research Station, Hunsur-571105, Mysuru, Karnataka

Raghavendra K. P.
ICAR-National Institute for Research on Commercial Agriculture, Research Station, Hunsur-571105, Mysuru, Karnataka

Ramakrishnan S.
ICAR-National Institute for Research on Commercial Agriculture, Research Station, Hunsur-571105, Mysuru, Karnataka

Introduction:

Parthenium hysterophorus is one of the most troublesome invasive weed including the tobacco-growing belts of Mysuru and surrounding districts. It spreads rapidly along field bunds, roadsides and fallow lands, competing with crops for nutrients, moisture and light. Heavy infestation around tobacco fields also interferes with farm operations and acts as a reservoir for pests and allergens affecting farm workers. In recent years, the occurrence of **parthenium rust disease,** caused by the fungus *Puccinia abrupta var. partheniicola*, has been noticed in several parts of Karnataka. This disease infects parthenium plants naturally and suppresses their growth and seed production, offering a promising eco-friendly option for weed management.

Parthenium rust is a fungal disease that specifically attacks parthenium weed. It appears as: small yellow to brown pustules on leaves, stems and petioles; drying and curling of infected leaves there by reducing plant vigour resulting in stunted growth and ultimately premature dying of plants in severe infection (*Sreeramakumar, 1998)*. Under humid and mild temperature conditions, the disease spreads quickly from plant to plant through wind-borne spores.


Parthenium rust found in tobacco fallow of ICAR-NIRCA Research station, Hunsur, Karnataka

About the Pathogen/ Bio-Control Agent

The fungal pathogen *Puccinia abrupta* **var.** *partheniicola*, commonly known as the **parthenium winter rust,** was rediscovered in India on an epiphytotic scale near Bengaluru, Karnataka, in February 2023, marking a significant development in the biological control of the invasive weed *Parthenium hysterophorus*. This rust has been observed in Karnataka for consecutive seasons (2023, 2024, and 2025), indicating its persistence in the region *(Sreeramakumar, 2024) and also observed in the zinger fallow lands of Hosur dist (Tamil Nadu)*. ***Puccinia abrupta*** **var.** ***partheniicola*** (parthenium rust) is a highly host-specific rust fungus. It's known hosts are mainly confined to the genus **Parthenium** (family Asteraceae).

Parthenium hysterophorus* L.** is the principal and most widely reported host worldwide (India, Australia, Americas, Africa). Other reported/experimental hosts includes ***Parthenium argentatum and other ***Parthenium* spp.** Notably, no confirmed infection on tobacco or major cultivated crops was reported. Further, it does not naturally infect other common Asteraceae weeds in field conditions. The rust is considered **highly host-specific,** which is why it can be explored as a **biological control agent against parthenium weed** without risk to crops like tobacco, cereals, pulses, or vegetables (Sreeramakumar and Evans, 2005).

Scenario in Tobacco

Parthenium infestation is common at Mysuru, Karnataka region especially in FCV tobacco fields, particularly along field borders and irrigation channels; uncultivated patches near curing barns and roadsides adjoining to tobacco farms. During winter, when the crop is harvested, the severity of parthenium observed. The parthenium rust infestation observed till the initiation of next season. The disease develops best under moderate temperatures (20–30 °C) with high relative humidity. The spread is positive in dense parthenium growth and in shaded and moist field margins. Monsoon and post-monsoon periods often show higher infection levels. The presence of rust disease on parthenium can reduce weed density naturally; which lower seed production and future infestation. The reduction of parthenium minimize competition for soil moisture and nutrients and the rust also support eco-friendly and low-cost weed management. This is especially useful in tobacco cultivation where excessive herbicide use is discouraged due to crop sensitivity and environmental concerns. Parthenium rust should be viewed as a beneficial natural agent. Farmers and extension workers can support its spread by **avoiding indiscriminate herbicide spraying** on infected parthenium patches.

Mass Production

Scientists are exploring the parthenium rust as a **classical biological control agent** because of its strong host specificity to *Parthenium hysterophorus*. Attempts were made to multiply spores under controlled conditions and release them in heavily infested areas. However this rust fungus is difficult to mass-produce because of its obligate parasitic nature (grow only on living host plants). It requires live parthenium plants with specific humidity and temperature for spore production, further the shelf life of spores also short. When compared to the beetle *Zygogramma bicolorata*, rust has **not yet reached operational mass-release programmes** in India. In future, development of workable mass multiplication techniques, spore formulation techniques; community-level inoculation methods in wastelands and integration with other biocontrol agents may make this as effective bio-control agent.

Conclusion

The natural occurrence of parthenium rust offers an encouraging, environment-friendly opportunity to suppress parthenium weed especially in tobacco-growing areas of Mysuru. By developing suitable mass production and distribution techniques and integrating it with existing weed management practices, farmers can reduce weed pressure and reliance on chemicals, contributing to sustainable tobacco cultivation in the region.

References

- Sreeramakumar, P. (2024). The exotic rust fungus *Puccinia abrupta* var. *partheniicola* on the invasive alien weed *Parthenium hysterophorus* in India: rediscovery and first report of an epiphytotic. *CABI Agriculture and Biosciences.* 5: 37. https://doi.org/10.1186/s43170-024-00242-1.

- Sreeramakumar, P. and Evans, H. C. (2005). The mycobiota of *Parthenium hysterophorus*in its native and exotic ranges: opportunities for biological control in India. In: *Proceedings of Second International Conference on Parthenium Management held at Bangalore (Karnataka)*, 5-7 December 2005, (Eds. Prasad et al.). pp: 107-113.

- Sreeramakumar, P. (1998). Biological suppression of Parthenium. In: *Biological suppression of plant diseases, phytoparasitic nematodes and weeds.* (Eds. S.P. Singh and S.S. Hussaini). Project Directorate of Biological Control, Bangalore, India. pp: 192-210.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

NAVODHAYA J V
Research scholar
Division of Plant Physiology,
ICAR-Indian Agricultural
Research Institute, New Delhi.

ARTICLE ID: 20

PHOSPHATE STARVATION RESPONSE REGULATED BY SUGARS IN PLANTS

1. Introduction

An essential but frequently limiting macro-nutrient in soils, phosphorus (P) is largely absorbed as inorganic phosphate (Pi), having a powerful limiting effect on plant growth and productivity. Plants under Pi deficiency activate a coordinated phosphate starvation response (PSR) that includes the changes in root architecture, expression of high-affinity Pi transporters, a metabolic reprogramming, and increased Pi recycling. It is already established that these PSR outputs are not activated by Pi status alone and are highly regulated by sugar availability and sugar signaling pathways, in particular, sucrose transported between shoots and roots 2. Summary of phosphate starvation responses (PSR)

2. Overview of phosphate starvation responses (PSR)

Classical PSR traits include:

1. High-affinity Pi transporter (PHT1 family) and Pi remobilization enzyme (purple acid phosphatases, ribonucleases) induction.
2. Physiological changes of root system architecture, including primary root growth inhibition and lateral root and root hair development to expand soil exploration.
3. Changes in photosynthesis and respiration, replacement of phospholipids with galacto- and sulfolipids, the accumulation of anthocyanins and reactive oxygen species (ROS).

A key transcriptional Arabidopsis Pi signaling module comprising the MYB transcriptional factor PHR1, associated microRNA miR399, and ubiquitin-conjugating enzyme PHO2, are also involved in controlling Pi uptake and translocation, via regulating PHT1 transporters and other genes related to Pi. These Pi-specific parts interconnect with more global carbon (C) and sugar communication systems, suggesting intensive C P nutritional crosstalk

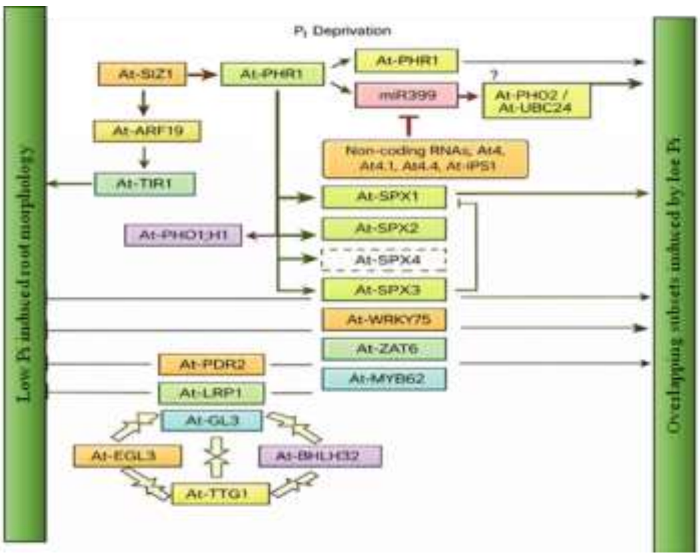


Fig 1. A model for the plant Pi regulon.

For simplicity, the interactions of genes that are induced (heavily outlined boxes), do not respond (lightly outlined boxes) or are repressed (dashed boxes) by Pi deficiency in arabidopsis are shown. At-SIZ1 (SAP and Miz1 domain-containing SUMO E3 ligase 1); At-PHR1 (PHosphate Starvation Response 1); At-PHF1 (PHosphate transporter traffic Facilitator 1); miR399 (MicroRNA 399); At-PHO2/At-UBC24 (PHOSPHATE 2/Ubiquitin-Conjugating Enzyme 24); At4, At4.1, At4.4 (phosphate starvation-induced non-coding RNAs); At-IPS1 (INDUCED BY PHOSPHATE STARVATION 1); At-SPX1, At-SPX2, At-SPX3, At-SPX4 (SYG1/Pho81/XPR1 domain-containing proteins 1–4); At-PHO1/At-PHO1;H1 (PHOSPHATE 1); At-WRKY75 (WRKY transcription factor 75); At-ZAT6 (Zinc finger of Arabidopsis thaliana 6); At-MYB62 (MYB domain transcription factor 62); At-ARF19 (Auxin Response Factor 19); At-TIR1 (Transport Inhibitor Response 1); At-PDR (PHOSPHATE DEFICIENCY RESPONSE 2); At-LRP1 (LATERAL ROOT PRIMORDIUM 1); At-GL3 (GLABRA 3); At-EGL3 (ENHANCER OF GLABRA 3); At-TTG1 (TRANSPARENT TESTA GLABRA 1); At-bHLH32 (basic Helix–Loop–Helix transcription factor 32).

3. Sugar as a systemic modulator of PSR.

3.1 Sugar is required for PSR.

Previous genetic and physiological research on Arabidopsis showed that exogenous sugars are required to induce PSR traits to their maximum in the case of Pi deficiency. Karthikeyan et al. (2007) demonstrated that normal responses to Pi starvation, such as the typical root architectural changes and phosphate starvation-induced (PSI) genes, cannot occur without sugar; absent sugar, these responses are inhibited with low extracellular Pi. Correspondingly, experiments that regulated carbohydrate concentrations in the media of growth showed that more supply of sucrose to roots in low-Pi conditions promotes the expression of Pi-sensitive genes and amplifies morphological PSR phenotypes. Genetic and genomic analysis has proven that sucrose is a universal controller of Pi-starvation responses. Transcriptomics were employed by Lei et al. (2011) to reveal that the availability of sucrose globally modulates PSR genes expression, and it indicates that sucrose is not just a simple source of energy but a signal that coordinates PSR on a whole-plant basis.

3.2 Sucrose induces shoot-root communication.

When Pi is deficient, photosynthetic leaves allocate carbon and export more sucrose to the roots, which provides systemic information on the status of the shoot PI and energy. Pi-starvation effect on root developmental reactions can also be recreated by adding sucrose to the root media, which points to a model whereby Pi starvation signal mobilized by shoots is transported to the root system to stimulate and enhance PSR. Recent research reveals that the local Pi concentration interacts with the supply of sucrose to fine-tune the root responses, which implies that plants combine both local and systemic signals to optimize the uptake of Pi.

4. Pathways of sugar signaling in PSR

4.1 Hexokinase dependent sugar sensing.

One of the most important glucose sensors, HXK1, is a widely acting sugar signaling protein incorporating sugar status into developmental and stress responses. Transcriptomic analyses have also evidence of disturbed HXK1 and other signaling elements expression under Pi starvation, and hexokinase-dependent sugar perceptions have been proposed to tune networks of PSR genes. The sugar sensor gene HXK1 increases in response to low levels of sucrose in the manipulation of Pi deficiency, showing that sugar sensing alters the balance between growth and photosynthesis and stress response in conditions where Pi is a limiting factor.

4.2 SnRK1 and Tre6P network

The SnRK1 (SNF1-related kinase 1) and trehalose-6-phosphate (Tre6P) signaling hub is a close indicator of sucrose availability and balances energy status and carbon allocation. Though sugar starvation experiments have provided the majority of mechanistic information, SnRK1-Tre6P signaling has been linked to the orchestration of responses to compounding sugar and nutrient stresses, such as Pi deficiency. In rice, sugar-related mutant alterations in cell-wall biosynthesis-associated gene (e.g., OsCSLF6) regulate the levels of sucrose and the expression of Pi signaling genes including OsIPS1 and

OsPHO2, which further implicates a relationship between carbon metabolic regulation and Pi signaling.

4.3 Post-transcriptional and translational regulation

The sugar signaling also occurs at post-transcriptional levels such as the regulation of the mRNA stability, the translation and the protein turnover. Not only is transcriptional regulation of the biosynthetic genes, but post-transcriptional mechanisms to finely tune enzyme abundance and activity are involved in the modulation of anthocyanin biosynthesis, ROS metabolism and lipid remodeling under Pi starvation.

5. Crosstalk between sucrose and canonical Pi signaling (PHR1–miR399–PHO2)

PHR1 regulates the production of miR399 by releasing the miR399 native PHR1 in response to Pi deprivation, miR399 represses PHO2, and PHO2 can regulate the expression of Pi transporters and other proteins associated with Pi. The presence of sugar changes the expression of most of the PHR1 target genes and Pi transporters indicating that sucrose signaling integrates into or regulates this central Pi signaling pathway. An example is that the induction of PHT1 family transporters as well as PHF1 is influenced by the levels of sucrose. They are able to control the expression of negative regulators like NLA1 (Nitrogen Limitation Adaptation 1) and hence the ability to increase or decrease Pi uptake capacity in accordance with combined C and P status. On a systems level, it is indicated that overlapping sets of many genes that respond to Pi and to sucrose are formed, meaning that transcription factors across sugar signaling pathways interact with PHR1-regulated networks. This combination makes sure that the process of Pi acquisition and remobilization is synchronized with the supply of carbon to the plant, so that discrepancies between energy requirements and the supply of nutrients will not be produced.

6. Physiological effects of sucrose on PSR outputs

6.1 System architecture and development.

Pi deficiency has a powerful modulatory effect on root system responses to sugar supply. Pi starvation generally suppresses primary root growth and stimulates the growth of lateral roots and the growth of root hair in Arabidopsis, although these responses are significantly decreased when the sugar supply is constraining. Pi-deficiency-induced root remodeling is improved by Pi-deficiency-induced root remodeling by supplemental sucrose, which suggests that Pi-deficiency-induced root remodeling is positively regulated by sucrose.

6.2 Photosynthesis and energy allocation

Pi starvation has effects on photosynthesis by changing the availability of ATP and Pi to the Calvin cycle and photophosphorylation. Recent transcriptomic studies indicate that in the adequate supply of sucrose, photosynthesis-related genes and chlorophyll metabolism are suppressed during Pi deficiency, and additional ATP is directed towards stress responses but not development. Conversely, photosynthesis genes may be more or less upregulated under the conditions of the scarcity of carbohydrates (sucrose limitation). This implies that the availability of sucrose assists in regulating the distribution of ATP and reducing power among plants between growth, defense and Pi acquisition under stress.

6.3: Accumulation of anthocyanin, ROS and lipid remodeling.

Pi starvation usually leads to accumulation of anthocyanin and alteration of ROS production, which are significant in stress acclimation and antioxidant defense. Pi deficiency induces the synthesis of anthocyanin using sucrose; in the situation of a low concentration of sucrose, the anthocyanin biosynthesis pathways and the ROS-related genes are less activated resulting in a decreased level of anthocyanin and ROS. Membrane lipid metabolism during Pi starvation is also regulated by Sucre availability in the contribution to Pi cycling through the phospholipid-galactolipid pathway.

7. Signalling of carbon and phosphorus.

The cross regulation of carbon metabolism and Pi signaling is one of the key axes of plant nutrient homeostasis. Rice and Arabidopsis mutations in carbon metabolism (e.g., OsCSLF6) have been found to modify the amount of sucrose and consequently the expression of Pi-starvation regulating genes (e.g., IPS1, INDUced by phosphohostile starvation 1) and PHO2, demonstrating that carbon metabolic status contributes to Pi regulatory circuits. On the other hand, the starvation of Pi may provide feedback on the carbon metabolism affecting the levels of starch and sucrose, respiration, and the growth dynamics. Sugar signaling can therefore be considered as an integrator, such that plants can detect carbon and Pi availability and respond by adjusting development, metabolism and gene expression. This interaction is essential in natural soils where there are simultaneous changes in light, carbon provision, and Pi availability and there are significant implications of this interaction in enhancing crop use of Pi through low-fertilizer agriculture.

8. Conclusions and future directions

All in all, it is possible to say that sucrose is a metabolic resource and a signaling molecule that controls phosphate starvation reactions on morphological, physiological, and molecular levels. Among the open questions, one can recognize defining the specific molecular connections between sucrose sensors (HXK1, SnRK1–Tre6P) and canonical Pi regulators (PHR1–miR399–PHO2) as well as how sugar-dependent post-transcriptional regulation has been involved in shaping PSR in various tissues and developmental stages. This will be critical in future work involving the integration of genetics, multi-omics, and modeling in various crops to take advantage of sugar -Pi signaling crosstalk to breed plants with an improved efficiency of Pi acquisition and utilization under sustainable fertilization regimes.

References

- Bari, R., Datt Pant, B., Stitt, M., & Scheible, W. R. (2006). PHO2, microRNA399, and PHR1 define a phosphate-signaling pathway in plants. *Plant Physiology*, 141(3), 988–999.
- Chen, X., Wang, M., Tian, Q., Liu, L., Wang, H., Song, X., ... & Han, X. (2025). The role of sucrose in phosphate starvation response: transcriptomic and physiological insights in *Arabidopsis thaliana*. *BMC Plant Biology*, 25(1), 1606.
- Hammond, J. P., & White, P. J. (2011). Sugar signaling in root responses to low phosphorus availability. *Plant Physiology*, 156(3), 1033–1040.
- Jin, C., Fang, C., Yuan, H., Wang, S., Wu, Y., Liu, X., ... & Luo, J. (2015). Interaction between carbon metabolism and phosphate accumulation is revealed by a mutation of a cellulose synthase-like protein, CSLF6. *Journal of Experimental Botany*, 66(9), 2557–2567.
- Karthikeyan, A. S., Varadarajan, D. K., Jain, A., Held, M. A., Carpita, N. C., & Raghothama, K. G. (2007). Phosphate starvation responses are mediated by sugar signaling in Arabidopsis. *Planta*, 225(4), 907–918.
- Lei, M., Liu, Y., Zhang, B., Zhao, Y., Wang, X., Zhou, Y., ... & Liu, D. (2011). Genetic and genomic evidence that sucrose is a global regulator of plant responses to phosphate starvation in Arabidopsis. *Plant Physiology*, 156(3), 1116–1130.
- Rouached, H., Arpat, A. B., & Poirier, Y. (2010). Regulation of phosphate starvation responses in plants: signaling players and cross-talks. *Molecular Plant*, 3(2), 288–299.
- Wang, K., Li, M., Zhang, B., Chang, Y., An, S., & Zhao, W. (2023). Sugar starvation activates the OsSnRK1a–OsbHLH111/OsSGI1–OsTPP7 module to mediate growth inhibition of rice. *Plant Biotechnology Journal*, 21(10), 2033–2046.
- Wang, M., Zang, L., Jiao, F., Perez-Garcia, M. D., Ogé, L., Hamama, L., ... & Chen, J. (2020). Sugar signaling and post-transcriptional regulation in plants: an overlooked or an emerging topic? *Frontiers in Plant Science*, 11, 578096.
- Xiao Juan Yang, & Finnegan, P. M. (2010). Regulation of phosphate starvation responses in higher plants. *Annals of Botany*, 105(4), 513–526.
- Yang, X. J., & Finnegan, P. M. (2010). Regulation of phosphate starvation responses in higher plants. *Annals of Botany*, 105(4), 513–526.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

ARTICLE ID: 21

POINT OF CARE DIAGNOSIS OF PLANT DISEASES

AUTHORS' DETAILS:

Shweta
Department of Plant Pathology, College of Agriculture, GB Pant University of Agriculture and Technology, Pantnagar- 263145, Uttarakhand, India

Introduction

Plant diseases are known to reduce worldwide crop productivity by 20-40%, costing USD 220 billion each year. It is therefore important to develop more efficient technologies to detect crop diseases and effectively link them to decision bodies to efficiently deploy the necessary responses and safeguard agricultural systems to feed the world's population which is expected to reach 9.7 billion by 2050. In the absence of resistance, pathogen detection and disease diagnosis in the field is an invaluable asset for the efficiency of pest management programs and lessen crop losses. The effectiveness of many integrated pest management strategies is highly dependent on the availability of fast, sensitive, and specific diagnostic methods. Point-of-care (POC) diagnosis of plant diseases is defined as a rapid evaluation method for pathogen detection, directly to the desired analysis site. It refers to the ability to rapidly and accurately detect plant diseases on-site, in real-time, using portable diagnostic tools or methods.

Need for POC diagnosis

- Samples are screened for disease at the sampling point
- The results are displayed within a few minutes to hours
- Timely decisions can be taken on management practices against particular pathogen/pest
- Requires a tiny sample size for the detection
- Give sensitive and accurate results
- Mostly automatic and hand-free sample preparation is there
- Convenient, as crop field locations can be far away from analytical laboratory setups and sample transport can pose logistical problems

Different methods for point-of-care diagnosis of plant diseases

Lateral flow assay

1. Protein-based POC disease diagnosis

Also known as lateral flow immunochromatographic assays, these are simple paper-based devices that detect the presence (or absence) of a target analyte in a liquid sample. Analytes (antigenic or pathogenic molecules) are separated chromatographically and then recognized using either antibody or nucleic acid-based probes. Lateral flow kits are easy for readymade use by the growers to make in situ decisions about the application of sprays. The cost of kits is minimal as compared to Polymerase chain reaction (PCR) and Enzyme-linked immune sorbent assay (ELISA) methods.

2. Nucleic acid (NA) based POC disease diagnosis

Nucleic acid extraction, amplification, detection, and validation are the four main steps needed for the development of a reliable protocol that is suitable for point-of-care analysis. And these steps are time-consuming if are performed conventionally. Therefore, NA-based POC methods are developed on the fact to minimize the time duration that is required for performing these steps individually.

For nucleic acid extraction, methods like magnetic bead extraction can be used which relies on using magnetic beads with a coating that can bind with nucleic acids for example Carboxylate-modified magnetic beads capture molecules containing amino group and OligoNT coated magnetic beads hybridize with mRNA tail. Similarly, Microneedle patches (MN-patches) made up of PVA (polyvinyl alcohol) can be attached to plant surfaces sufficiently strong enough to break the cell wall of plant leaf tissues to release plant or pathogenic DNA.

PCR-based amplification methods applied for POC plant pathogen detection include Nested-PCR, Real-time PCR, Digital PCR, etc. but these are more time-consuming than the isothermal-based amplification methods like Loop-mediated isothermal amplification (LAMP), Rolling polymerase amplification (RPA), Rolling circle amplification (RCA), displacement amplification (SDA), and Helicase-dependent amplification (HDA). For Nucleic acid detection Fluorescence-based methods, Surface-enhanced Raman scattering (SERS), colorimetric method, Bioluminescence essay in real-time (BART), etc. are used to get instant results.

Sensor-based POC disease diagnosis

1. E-NOSE

The electronic nose (e-nose) is a device that mimics the human olfactory system (Sun *et al*., 2019; Zhong, 2019). The specific and characteristic VOCs that are emitted by pathogenic microorganisms provide unique odor fingerprints that can be used as biomarkers for pathogen identification and discrimination.

A typical e-nose system comprises three major components, including:

1) Sample handling and odor delivery system
2) Detection system (sensor array)
3) Data processing in computing system

2. E-EYE (Optical sensor)

This method is based on imaging methods which include the acquisition of diseased plant images with views ranging from proxy-detection (mm to m) to tele-detection (cm to km). It is more reliable for in-vitro monitoring as there is biological control of the entire plant-pathogen interaction and lighting conditions during acquisition.

3. Acoustic sensor

It is an emerging technique as proof-based studies are lacking. Plants can spontaneously generate sound waves with relatively low frequencies of 50–120 Hz. Like humans and other animals, plants may have internal preferred frequencies of vibration. Plants can also absorb and amplify specific external sound frequencies. Yang *et al*. (2014) used AE technology to design a method for diagnosing agricultural disease stress. The results of their study showed that the continuous detection of AE signals of a diseased/stressed plant was dissimilar to healthy plants.

4. Wearable sensors

Because of its exceptional mechanical compatibility, a wearable plant sensor can be mounted to the plant's surface with ease. It contains nanoelectronics circuits that provide wireless communication via low concentrations of volatile organic molecules in real-time. There are wearable carbon nanotube-based sensors available for agricultural usage that measure plant volatile organic compounds (VOCs), such as polyethylene. Microneedles are another type of wearable sensor, that can reach inside the plants. These are capable of extracting sap, detecting sap flow rate, and analyzing its physicochemical properties such as pH and electric conductivity.

Challenges

These methods are not widely used for field screening or analyzing plant material, most likely due to technological constraints, especially when trying to develop a procedure for routinely identifying different diseases in different plant species. Furthermore, the relatively high cost of some of the methodologies, particularly when applied to large-scale studies, can be an issue. Some of these methods need to be user-friendly to be widely adopted and effectively implemented. Optical sensors are challenging to utilize in fields due to potential pressures and uncontrolled environments for optical acquisition. Wearable sensors, on the other hand, are flexible tools and compatible with plant conditions but their use to understand some of the plant's physiological responses, such as water, nutrients, and light has limitations.

Conclusion/Summary

POC diagnosis plays a crucial role in global health and food security. In comparison to conventional diagnostic techniques, it is sensitive and fast. Advanced point-of-care diagnostics tools help in making timely disease management decisions and can aid in the early detection of emerging diseases or quarantine pathogens. Point-of-care technology is continually growing, with rapid advances in mobility, accuracy, and convenience of use. All of these traits could make POC the gold standard for pathogen diagnosis in the next years and it would pave the road for "sample-in-result-out" plant disease diagnosis, especially in remote or resource-limited areas.

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Neeraj Nagar
Department of Horticulture (Floriculture and Landscaping), College of Agriculture, Central Agricultural University, Imphal, Manipur, India - 795004.

Dr. Abhinash Moirangthem
Department of Horticulture (Floriculture and Landscaping), College of Agriculture, Central Agricultural University, Imphal, Manipur, India - 795004.

Dr. Punabati Heisnam
Department of Agronomy, College of Agriculture, Central Agricultural University, Imphal, Manipur, India - 795004.

Dr. Anok Uchoi
Department of Horticulture (Medicinal and Aromatic Plants), College of Agriculture, Central Agricultural University, Imphal, Manipur, India - 795004.

ARTICLE ID: 22

Role of Floriculture and Ornamental Plants in Mitigating Environmental Pollution

Abstract

Environmental pollution has emerged as a critical global concern due to rapid urbanization, industrial expansion, and escalating vehicular emissions, resulting in adverse impacts on human health, ecosystem stability, and climate regulation. While conventional pollution control technologies are effective, their high energy demand and operational costs limit widespread application, necessitating sustainable alternatives. Floriculture and ornamental plants, beyond their aesthetic value, offer significant potential as nature-based solutions for environmental pollution mitigation. These plants reduce airborne contaminants, particulate matter, and greenhouse gases through mechanisms such as stomatal uptake, surface deposition, phytodegradation, rhizospheric microbial activity, and carbon sequestration. Their morphological and physiological traits, including high leaf surface area, dense canopy architecture, and adaptability to diverse environmental conditions, enhance their effectiveness in both indoor and outdoor settings. Ornamental vegetation further contributes to microclimate regulation by moderating temperature, humidity, and airflow, thereby indirectly reducing pollutant formation and dispersion. The integration of ornamental plants into urban green infrastructure such as green roofs, vertical gardens, roadside plantations, and indoor landscapes provides a multifunctional, cost-effective, and socially acceptable strategy for improving environmental quality. Despite growing evidence supporting their pollution mitigation capacity, challenges remain in quantifying long-term field performance and standardizing assessment methodologies. Strengthening interdisciplinary research and evidence-based planning will be essential to maximize the environmental benefits of ornamental plants. Overall, floriculture-based green interventions represent a promising and sustainable approach to mitigating environmental pollution in rapidly urbanizing landscapes.

Keywords: Ornamental plants, Phytoremediation, Air pollution, Green infrastructure, Sustainability.

1. Introduction

As a result of its adverse effects on natural systems, human health, and climate dynamics, environmental pollution continues to be a major worldwide concern. Particulate matter (PM), volatile organic compounds (VOCs), nitrogen oxides (NO_x), sulphur dioxide (SO_2), and greenhouse gases like carbon dioxide (CO_2) and methane (CH_4) are among the airborne contaminants that significantly contribute to respiratory disorders, cardiovascular diseases, and climate change (Wroblewska & Jeong, 2021). Conventional pollution control technologies, such as chemical scrubbers, industrial filters, and catalytic converters, can effectively reduce pollutant loads, but they are often costly, resource-intensive, and energy-dependent. On the other hand, phytoremediation a natural remedy that uses plants and related microbial populations to eliminate, stabilize, or change environmental contaminants has become a viable, environmentally beneficial substitute.

Within this context, ornamental plants and floricultural species, widely used for aesthetic and cultural purposes, have significant yet underexplored potential in mitigating environmental pollution through multiple biological and physical mechanisms (Sharma *et al.*, 2025; Ali *et al*., 2013). Environmental degradation has accelerated due to rapid urbanization, industrial growth, and rising vehicle emissions, especially in densely populated areas. The World Health Organization claims that millions of premature deaths are caused by exposure to contaminated air each year, underscoring the critical need for alternate mitigation techniques that support traditional pollution management systems (WHO, 2023).

Ornamental plants are increasingly recognized as providers of ecosystem services beyond aesthetics, including air quality improvement, carbon sequestration, and microclimate regulation in both urban and indoor environments. Ornamental species are interesting candidates for sustainable environmental management solutions because they have the extra benefit of societal acceptability and widespread integration into built settings, in contrast to conventional phytoremediation species that are usually utilized for soil decontamination. With a focus on air pollutant absorption, greenhouse gas removal, indoor air purification, and urban pollution mitigation, this review summarizes the state of the art about the biochemical pathways and physical processes by which ornamental plants reduce environmental pollution (Khan *et al.*, 2021)

Because of their unique biological traits such as quick growth, fast leaf turnover, and climate adaptability- floriculture plants are especially well-suited for use in contaminated areas. Ornamental plants can be easily placed into streetscapes, rooftops, indoor areas, and academic campuses, allowing for quick contact with pollutants, in contrast to forest species that need lengthy establishment times (Escobedo *et al*., 2011). Due to their low energy consumption and capacity to operate as continuous, self-regenerating systems, plant-based solutions have gained attention in recent environmental research advancements. In addition to directly absorbing pollutants, ornamental plants also influence microclimatic factors like temperature, humidity, and wind speed, which have an indirect impact on the dispersion and concentration of pollutants (Nowak *et al*., 2014).

2. Phytoremediation Mechanisms in Ornamental Plants

A variety of plant-mediated techniques, including adsorption, absorption, phytodegradation, phytovolatilization, and phytoextraction, are used in phytoremediation to lower pollutant concentrations in the air, soil, and water. These mechanisms stem from the morphological and physiological characteristics of plants, which dictate their ability to interact with environmental pollutants. Ornamental plants' ability to phytoremediate contaminants is controlled by integrated physiological, biochemical, and structural mechanisms. Enzymes like peroxidases, dehydrogenases, and oxygenases can participate in oxidative and reductive pathways that convert ingested pollutants at the cellular level. These changes lessen the toxicity of pollutants and make it easier for them to be incorporated into secondary metabolites or sequestered within vacuoles Salt *et al.*, 1998).

The main ways that plants absorb gaseous and particle pollutants are through their leaf surfaces and stomatal apertures, which allow them to come into direct contact with airborne pollutants. After being absorbed, contaminants may be converted into less harmful substances, retained in tissues, or digested by plant enzymes. Additionally, the surface morphology of leaves, such as surface roughness, trichomes, and waxy cuticles, affects how well particulate matter and gaseous chemicals are captured. Complex interactions between the rhizosphere (roots and related microorganisms) and the phyllo sphere (above-ground plant portions) are another aspect of phytoremediation systems. Microbial communities in the root zone can enhance the breakdown of absorbed organic pollutants and promote nutrient cycling, thereby contributing to pollutant removal (Pilon-Smits, 2005).

The rhizosphere serves as a biologically active area where interactions between plants and microbes improve remediation efficiency beyond what plants might accomplish on their own. Additionally, plant developmental stages and phenological cycles have an impact on the effectiveness of phytoremediation procedures. Compared to senescent plants, actively growing ornamental species have higher metabolic rates and greater pollution uptake. This dynamic behaviour underscores the importance of proper maintenance practices, including pruning and replacement cycles, to sustain long-term pollution mitigation performance (Ali *et al., 2013).*

2.1. Air Pollutant Absorption and Deposition

Stomatal uptake and surface deposition play a major role in ornamental plants' absorption of air pollutants. Through stomatal apertures, gaseous pollutants including NO_x, SO_2, and VOCs enter leaf tissues and either undergo enzymatic modification or are trapped inside cellular structures. Particularly in species with large leaf surface area and textured surfaces, particulate debris physically attaches to leaf surfaces. These procedures successfully lower ambient concentrations and remove contaminants from the air column (Rai, 2016).

Species characteristics have a major impact on the efficiency of pollutant capture: species with larger stomatal densities show stronger uptake of gaseous pollutants, whereas broad-leaved plants with high surface area typically capture particulate matter more successfully than narrow-leaved species. The use of ornamental plants as natural biofilters for air quality control is based on the combined contribution of these biological and physical characteristics. Aerodynamic processes that are impacted by leaf geometry and canopy architecture also control particulate matter deposition on plant surfaces. Rough leaf textures and complex branching patterns increase turbulence within the canopy, promoting particle interception and sedimentation (Hofman *et al*., 2017).

Particulate pollutants may be retained in epicuticular waxes, where they remain immobile, or they may be carried away by precipitation after being deposited. This retention helps to enhance air quality over time by lowering resuspension into the atmosphere. However, too much buildup might reduce photosynthetic performance, highlighting the necessity of choosing species that strike a balance between physiological tolerance and pollutant capture (Saebo *et al*., 2012).

2.2. Removal of Greenhouse Gases

Through activities related to photosynthesis and plant growth, ornamental plants contribute to the mitigation of greenhouse gases like CO_2 and CH_4 in addition to capturing air pollutants. Plants take in CO_2 from the atmosphere during photosynthesis, use it to create organic biomass, and then release oxygen (O_2). This carbon assimilation helps mitigate climate change locally by lowering atmospheric CO_2 concentrations **(**Li *et al*., 2023).

Ornamental vegetation affects greenhouse gas dynamics through indirect processes including soil carbon storage and surface energy balance modification, which go beyond carbon dioxide absorption. By adding organic matter to the soil, root biomass improves soil structure and increases the potential for carbon sequestration, both of which have an impact on gas diffusion rates. Therefore, landscaped areas with decorative plants serve as localized carbon sinks, especially in urban settings where impermeable surfaces predominate (Lal, 2004).

By improving soil gas diffusion dynamics and encouraging methanotrophic microbial activity, emerging applications like Phyto capping the use of vegetation cover over waste sites employ plants to reduce methane emissions. These methods highlight the ability of plant systems, particularly ornamental species, to affect greenhouse gas fluxes in contaminated environments, even though they are more thoroughly researched in soil remediation contexts. By lowering ambient temperatures through evapotranspiration and shade, vegetated surfaces also alter microclimatic conditions. Lower temperatures indirectly lessen greenhouse forcing by reducing photochemical reactions that produce secondary pollutants like ozone (Bowler *et al.,* 2010).

3. Ornamental Plants in Air Pollution Control

The application of ornamental plants as air pollution mitigation tools spans indoor environments, urban green infrastructure, and bio-scrubbing systems. Their relevance stems from their capacity to reduce pollutant loads while simultaneously enhancing environmental aesthetics and psychological well-being. The deployment of ornamental plants as air pollution control agents is increasingly integrated into urban planning initiatives focused on sustainable development. Green roofs, vertical gardens, and roadside plantations utilize ornamental species to intercept pollutants at multiple atmospheric levels. These systems not only improve air quality but also enhance urban aesthetics and social well-being (Zhao *et al*., 2024).

Ornamental plant-based biofiltration systems have drawn interest as passive air purification solutions. Polluted air is channelled via plant substrates in these systems, where toxins are eliminated by plant absorption, microbial breakdown, and adsorption. Ornamental plants can be used as designed biofilters in commercial and institutional settings because of their capacity to adapt to small spaces (Irga *et al*., 2018).

Appropriate species selection, maintenance schedules, and interaction with constructed infrastructure are critical to the effectiveness of plant-based air pollution management. Because of their complementing pollution removal processes and functional variety, multispecies assemblages are frequently more successful than monocultures (Alonso *et al*., 2017).

3.1. Indoor Air Quality

Because of the buildup of volatile organic compounds (VOCs) including formaldehyde and benzene from building materials, furniture, and home goods, indoor air pollution is a persistent health risk. Under controlled conditions, potted ornamental plants have been shown to dramatically lower quantities of these volatile organic compounds (VOCs) in laboratory and chamber investigations. For example, in a controlled setting, the palm species *Chamaedorea elegans* effectively eliminated formaldehyde from indoor air, with removal efficiencies ranging from 65% to 100%, depending on exposure length and concentration. Comparative analyses of potted plants such *Epipremnum aureum, Chlorophytum comosum, Syngonium podophyllum, and Cordyline fruticosa* have demonstrated VOC removal efficiency of up to 77%, with significant drops in CO_2, $PM_{2.5}$, and PM_{10} concentrations (Kim *et al*., 2018; Irga *et al.*, 2018).

This cooperative plant-microbe system emphasizes how crucial soil health is to optimizing the advantages of indoor air purification. However, variables like ventilation rate, plant density, and maintenance procedures affect increases in indoor air quality. Plants are complimentary elements of integrated indoor environmental management techniques, even if they might not be able to completely replace mechanical ventilation (Cummings & Waring, 2020).

4. Ornamentals in Outdoor Urban Pollution Mitigation

By reducing ambient particulate matter and gaseous pollution concentrations, urban vegetation-which includes decorative trees, shrubs, and green walls-serves as an essential aspect of urban ecosystem services. Under field conditions, urban vegetation can lower PM concentrations by roughly 16.5-26.7%, NO_x by 13.9-36.2%, and SO_2 by 20.5-47.8%, according to meta-analytical evaluations. These reductions are achieved through the combined actions of pollutant deposition on leaf surfaces, stomatal uptake, and structural interception (Escobedo *et al.*, 2011)

Ornamental vegetation-dominated urban environments contribute to spatial variation in the dispersion of pollutants, resulting in areas where human populations are less exposed. In vegetated environments, tree canopies and shrub strata modify airflow patterns, decreasing wind speed and increasing pollution deposition. In street canyons, where pollution buildup poses serious health hazards, this spatial modulation is especially crucial (Gromke & Ruck, 2012).

Ficus, Areca palm, Peace lily, and money plant are examples of species that are frequently employed in public landscapes because of their improved ability to absorb particulate matter and lower pollutant concentrations in outdoor settings. Additionally, dense plants can provide natural barriers that reduce exposure to traffic-related pollutants, particularly PM and NO_2, along highways and urban corridors (Dubey *et al*., 2025)

Ornamental plantings that promote urban biodiversity further strengthen ecosystem resilience, guaranteeing long-term pollution reduction in the face of shifting environmental conditions. Diverse plant assemblages provide functional stability by lowering susceptibility to diseases, pests, and weather stress (Gillner *et al*., 2015).

5. Noise and Dust Reduction by Ornamental Vegetation

In addition to reducing air pollution, beautiful vegetation helps urban areas reduce noise and dust. Through processes like reflection, diffraction, and absorption, vegetative barriers made up of thick rows of trees and bushes attenuate sound waves, resulting in quantifiable reductions in noise levels from industrial operations and traffic. In residential and business areas, leaf surfaces simultaneously reduce dust deposition by capturing dust and airborne particulates (Saebo *et al*., 2012).

When used appropriately in landscape designs, species like *Ficus spp., Alstonia spp., Nyctanthes spp., and Hamelia spp*. have been shown to offer dust trapping and noise buffering. Including these plants in urban designs promotes better environmental quality and community well-being, especially in areas close to sources of noise and pollution (Fang & Ling, 2003).

Both physical interception and electrostatic attraction of particles to leaf surfaces are ways that ornamental plants reduce dust. Research shows that moisture content and leaf surface charge affect dust retention capacity, emphasizing species-specific variations in efficacy. Frequent irrigation or rainfall makes it easier to remove trapped dust, restoring leaf functionality and allowing for further cycles of mitigation. Incorporating decorative plants into locations that are prone to noise and dust, like industrial zones, roads, and construction sites, offers a low-cost, multipurpose mitigation method that also improves public acceptance and visual quality (Rai, 2016).

Conclusion

This review underscores the significant and multifaceted role of floriculture and ornamental plants as sustainable, nature-based solutions for mitigating environmental pollution in both urban and indoor environments. Beyond their conventional aesthetic value, ornamental plants demonstrate considerable capacity to reduce air pollutants, particulate matter, greenhouse gases, noise, and dust through integrated mechanisms such as phytoremediation, surface deposition, rhizospheric microbial interactions, and microclimate regulation. Their adaptability, rapid establishment, and social acceptability make them particularly suitable for incorporation into green infrastructure systems, including green roofs, vertical gardens, roadside plantations, and indoor landscapes. While existing evidence highlights their effectiveness in improving environmental quality, limitations related to species-specific performance, long-term field validation, and standardized assessment methodologies remain. Overall, the strategic integration of ornamental plants into environmental management frameworks offers a cost-effective, resilient, and ecologically sound approach to pollution mitigation, supporting sustainable urban development and enhanced human well-being in the face of increasing environmental pressures.

References

- Ali, H., Khan, E., & Sajad, M. A. (2013). Phytoremediation of heavy metals-Concepts and applications. *Chemosphere, 91*(7), 869-881. https://doi.org/10.1016/j.chemosphere.2013.01.075
- Alonso, R., Vivanco, M. G., González-Fernández, I., Bermejo, V., Palomino, I., Garrido, J. L., Elvira, S., & González-Castanedo, Y. (2017). Modelling the influence of peri-urban trees on air quality. *Science of the Total Environment*, *573*, 1136-1144. https://doi.org/10.1016/j.scitotenv.2016.09.076
- Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review. *Landscape and Urban Planning*, *97*(3), 147-155. https://doi.org/10.1016/j.landurbplan.2010.05.006
- Cummings, B. E., & Waring, M. S. (2020). Potted plants do not improve indoor air quality: A review and analysis of reported VOC removal efficiencies. *Journal of Exposure Science & Environmental Epidemiology*, *30*(2), 253-261.

https://doi.org/10.1038/s41370-019-0175-9

- Escobedo, F. J., Kroeger, T., & Wagner, J. E. (2011). Urban forests and pollution mitigation. *Environmental Pollution, 159*(8-9), 2078-2087. https://doi.org/10.1016/j.envpol.2011.01.010
- Fang, C. F., & Ling, D. L. (2003). Investigation of the noise reduction provided by tree belts. *Landscape and Urban Planning, 63*(4), 187-195. https://doi.org/10.1016/S0169-2046(02)00190-1
- Gillner, S., Vogt, J., Tharang, A., Dettmann, S., & Roloff, A. (2015). Role of street trees in urban ecosystems. *Urban Forestry & Urban Greening, 14*(3), 642-650. https://doi.org/10.1016/j.ufug.2015.06.004
- Gromke, C., & Ruck, B. (2012). Pollutant concentration in street canyons. *Atmospheric Environment, 48*, 307-317. https://doi.org/10.1016/j.atmosenv.2011.10.059
- Hofman, J., Samson, R., Joosen, S., & Blust, R. (2017). Role of leaf traits in particulate matter capture. *Environmental Pollution, 223*, 362-371. https://doi.org/10.1016/j.envpol.2017.01.040
- Irga, P. J., Paull, N. J., Abdo, P., & Torpy, F. R. (2018). Indoor plant biofilters for air quality improvement. Atmospheric Environment, 173, 44-54. https://doi.org/10.1016/j.atmosenv.2017.10.048
- Khan, A. H. A., Kiyani, A., Mirza, C. R., Butt, T. A., Barros, R., Ali, B., Iqbal, M., & Yousaf, S. (2021). Ornamental plants for the phytoremediation of heavy metals: Present knowledge and future perspectives. *Environmental Research, 195*, 110780. https://doi.org/10.1016/j.envres.2021.110780
- Kim, K. J., Kim, H. H., & Lee, J. S. (2018). Removal of indoor air pollutants by ornamental potted plants and their associated microorganisms. *Horticulture, Environment, and Biotechnology, 59*(2), 185-193. https://doi.org/10.1007/s13580-018-0023-7
- Lal, R. (2004). Soil carbon sequestration impacts on climate change. *Science, 304*(5677), 1623-1627. https://doi.org/10.1126/science.1097396
- Li, X., Zhou, Y., Asrar, G. R., & Mao, J. (2023). Urban vegetation and its role in carbon sequestration and climate regulation. *Sustainability, 15*(9), 7452. https://doi.org/10.3390/su15097452
- Nowak, D. J., Hirabayashi, S., Bodine, A., & Greenfield, E. (2014). Tree and forest effects on air quality and human health. *Environmental Pollution, 193*, 119-129. https://doi.org/10.1016/j.envpol.2014.05.028
- Pilon-Smits, E. (2005). Phytoremediation. Annual Review of Plant Biology, *56*, 15-39. https://doi.org/10.1146/annurev.arplant.56.032604.144214
- Rai, P. K. (2016). Impacts of particulate matter pollution on plants: Implications for environmental biomonitoring. *Ecotoxicology and Environmental Safety, 129*, 120-136. https://doi.org/10.1016/j.ecoenv.2016.03.012
- Saebo, A., Popek, R., Nawrot, B., Hanslin, H. M., Gawrońska, H., & Gawronski, S. W. (2012). Plant species differences in particulate matter accumulation on leaf surfaces. *Science of the Total Environment, 427-428*, 347-354. https://doi.org/10.1016/j.scitotenv.2012.03.084
- Salt, D. E., Smith, R. D., & Raskin, I. (1998). Phytoremediation. *Annual Review of Plant Physiology and Plant Molecular Biology, 49*, 643-668. https://doi.org/10.1146/annurev.arplant.49.1.643
- Wood, R. A., Orwell, R. L., Tarran, J., Torpy, F., & Burchett, M. (2002). Potted plant–soil systems and indoor air pollution. *Water, Air, & Soil Pollution, 141*(1-4), 385-396. https://doi.org/10.1023/A:1021395108932
- World Health Organization. (2023). *Ambient (outdoor) air pollution*. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health
- Wroblewska, K., & Jeong, B. R. (2021). Effectiveness of plants and green infrastructure utilization in ambient particulate matter removal. *Environmental Sciences Europe, 33*(1), 110. https://doi.org/10.1186/s12302-021-00547-2

JUST AGRICULTURE
THE FUTURE OF AGRI INNOVATION

Just Agriculture Multidisciplinary *e- newsletter*

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

S. N Sabale
Assistant Professor, RSRS, Basmath, Vnmkv, Parbhani

R. G. Thorat
Senior Research Assistant, RSRS, Basmath, Vnmkv, Parbhani Maharashtra, India

ARTICLE ID: 23

PLANTING TECHNIQUES IN SUGARCANE

Abstract:
The India is the second-largest producer of sugarcane in the world, India has steadily increased its output potential over the past 20 years to meet the world's need for energy and sweeteners. The most crucial and labour-intensive step in sugarcane cultivation is planting. Most commercial planting methods use the flat planting, ridges and furrows, or ring pit techniques. It is common practise to vegetative propagated crops like sugarcane, setts with single bud to six buds, settling prepared from tissue culture, or single buds in nurseries. The researchers found that the setts with two buds have a germination rate of 65 to 70% and a higher yield. Although single-budded setts also give 70% germination if chemically treated, larger setts do survive inclement weather better. Modern sugarcane planting methods use partially or entirely automated planting devices. The most economical spacing and seed rate are determined by the variety, the planting period, as well as the soil fertility and climatic conditions of the area. the bud position while placement in the soil has effect on germination in single budded setts. 0^o to 90^o with respect to horizontal shown best results for germination and stalk height at 125 DAS and 180^o and 270^o position of bud have shown delayed in germination. Even today, more than 80% of the sugarcane planted in India, Brazil, Australia, and other countries throughout the world is done so by hand. These offer a peek of the modern sugarcane cultivation techniques used in India. The adoption of the best planting techniques is one of the most significant researchable priorities that may be developed to solidify the huge potential of sugarcane production towards enhanced sustainability. The paper reviews the most common used and popular sugarcane planting methods.

Keywords: *Sugarcane production, Climate requirement, Soil requirement, Planting methods*

1. Introduction

The cotton industry is India's largest agricultural sector; sugar is the second largest. It serves the households of almost 50 million farmers. About 525 sugar mills, 200 distilleries, and 260 cogeneration facilities make up the Indian sugar industry. Throughout 115 nations around the world have commercial sugarcane farms, which cover 26 million hectares and produce nearly 1900 million tonnes of sugar annually (FAOSTAT 2018). Despite the fact that sugar is the primary product derived from sugarcane, it is also used as a raw material for other products with added value like feed, fibre, and energy, particularly biofuel and cogeneration. Due to the manufacturing of ethanol and the cogeneration of electricity in sugarcane plants, sugarcane has become more significant to the national economy. For every 100 tonnes of crushed cane used in one sugar factory, approximately 10.0 tonnes of raw sugar, 30.0 (range 27.0-33.0) tonnes of bagasse, 4.5 (range 4.0-5.4) tonnes of molasses, 3.5-3.9 tonnes of filter/press mud, 0.3 tonnes of furnace ash, 1200 (range 1125-1300) litres of alcohol by molasses route, and 10,000 kW-h of excess electricity are produced (Shukla et al.,2017).

India, sugarcane is grown in two distinct agro-climatic regions: tropical and subtropical. About 45% of the area is in the tropical zone, and the remaining 55% is in the sub-tropical zone, where sugarcane is grown. Sugar is made from sugarcane, which provides around 80% of it, and sugar beet, which provides 20%. The sugarcane is labour intensive crop, requires human workers for various unit operations like planting, weeding, earthing up, fertilizer application, and harvesting. Labour shortage during planting, weeding and harvesting periods of sugarcane growing hamper agricultural operations causing crop losses. The labour-intensive methods, leads to considerable losses in crop production (Dharmawardene, 2006). Analysis of the cost components of sugarcane cultivation shows that harvesting and loading of cane comprise 35% of the costs followed by land preparation (21%), planting (16%), weeding (10%), fertilizer application (10%) and irrigation (8%). Timely planting with proper application of nutrients and plant protection improves crop stand as well as sugar yield. The planting methods largely affect the economics of sugarcane production. Planting technology includes harvesting and detrashing seed cane, preparation of seed, and placement of the planting material into well prepared seedbed. The effectiveness of planting is affected by quality and type of planting material, layout, spacing, seed rate, nutrients and method of placement. Mechanization of various operations reduces labour dependency and help in performing farm operations at proper time. Mechanization of the sugarcane planting has been affected through development of machines for different unit operations separately or in combination. The economics of sugarcane production are significantly impacted by the planting techniques. In India, sugarcane is often planted with row spacings between 60 and 75 cm, which is typical in the subtropical region, and between 80 and 120 cm, which is typical in the tropical belt. These spacings were selected by the farmers mostly because to the bullock power-based cultivation techniques and tools used in the sugarcane growing (Sundara, 2007). The genetic potential for tillering has not been completely utilised in sugarcane planting practises. In conventionally cultivated crops, inter-plant competition and unevenly distributed solar radiation tend to limit tillering and lead to greater mortality, which has a negative impact on stalk density and crop productivity in general (Shrivastava and Rai, 2007). This paper reviews the efforts made by research workers for modernization of sugarcane planting technology and the most common and popular approaches of sugarcane planting methods.

Methods of sugarcane planting:

The planting method of sugarcane is mainly selected on the basis of soil type, availability of irrigation facilities, drainage and available moisture in the soil. Trenches are usually made by tractor or country plough for sowing sugarcane. Different sugarcane-growing states in the nation employ various planting techniques. Some approaches are often used, while others are peculiar to a certain situation or location. The prevalent method of sugarcane planting are as follows:

Conventional methods of sugarcane planting

It is followed in the most of cultivation, but it is not completely manual. In the semi-mechanized system harvesting and distribution of seed in the furrow is done manually, maintaining good uniformity of seed spacing. The field layout is usually prepared by tractor drawn or animal drawn implements. Harvesting of plant cane is manually by machetes, followed by de-trashing. Transportation to the planting field where is cut into setts. Then setts are treated with insecticide and fungicide. The planting field is ploughed and layout of ridges and furrows prepared by animal drawn or tractor drawn ridger. The setts are laid on the ridges manually and then placed at furrow bottom in dry or wet condition. Needs to be covered with soil if planted dry, pressed by feet if planted in wet soil. The planting method requires 30 to 35 labour-days per hectare for detrashing, sett cutting and transportation. Another 5 labours for fertilizer application are required (Deshmukh at al., 2009) similar labour requirement was reported by (Yadav et al, 2004; Khedkar and Kamble, 2008).

Flat planting

The subtropical belt of India predominantly uses the flat planting method. According to tradition, the land is prepared by one or two deep ploughings to uproot the old and planking to break up clods and bring the soil to a fine tilth.

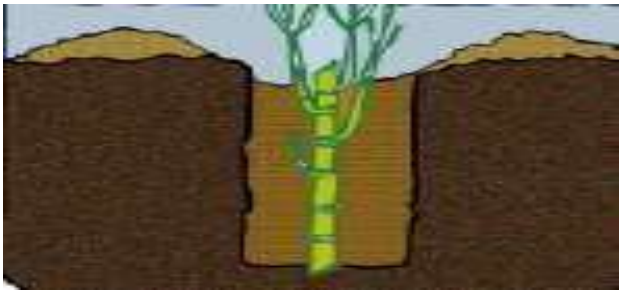
Sugarcane planting by flat planting method

The traditional method of deep tillage for sugarcane was reconsidered as a result of high production costs and a severe labour scarcity. To achieve a high cane yield, conservation tillage with two to three ploughings and planking compacting is sufficient. Compaction and recurrent ploughing disrupt the continuity of capillary pores and produce soil mulch, which aids in retaining soil moisture. For planting, the plough or tractor-drawn ridgers create shallow furrows that are 10-15 cm deep, and setts are then placed end to end or overlapped in these furrows. When the seed rate is lower and the variety's intermodal length is shorter, the placement of setts is done end to end. If the seed rate is larger and the setts have longer internodes, the overlapping type of sett placement is used. When a crop is planned for multi-ratooning, this is also done to get a high starting plant population. Approximately 60,000 two-bud setts and 40,000 three bud setts, if the setts quality is adequate, would be enough to plant one hectare of land and produce a satisfactory harvest under standard planting conditions. However, because bud breakage during handling and transportation is very common, 75,000 two-bud setts or 50,000 three- bud setts per hectare are deemed sufficient (Lal and Singh, 2007). Higher seed rates are recommended, especially in conditions of moisture stress, salt, and waterlogging. Given that sett weight varies with cultivars, it is preferable to count the number of setts per hectare rather than weight. Since the number of setts per unit row length is kept constant with reduced spacing more setts are planted per hectare. However, it is suggested to utilise more cane setts per unit row length when the spacing is widened. The soil is again crushed with a heavy wooden plank after the setts have been placed in the furrows in order to preserve soil moisture. Consequently, a layer of soil of 3 to 5 cm thick covers the setts. In north India, the germination rate of planted buds using this approach is quite poor and also takes a long period, especially in the autumn. For soils with limited irrigation and low to moderate fertility, this approach is advised.

Ridge and furrow method:

In intense irrigated sugarcane cultivation, the ridge and furrow planting method is the best. South India also use this technique. The method allows for simple irrigation, efficient soil aeration, and enough plant support. When the earthing up is done properly. Furrows and ridges are created on carefully prepared fields using tractor- or bullock-drawn ridges, maintaining a gap of 60 to 135 cm between each furrow. The most typical distance is 90 cm. For short duration early and shy tillering cultivars, low soil fertility, moisture stress or waterlogging, and late (summer), a closer spacing of 60–75 cm is preferred. In high fertility condition with effective irrigation systems and for long lasting, high tillering varieties, wider spacing is advised. To enable automated planting and harvesting processes, spacings of up to 150 cm can be used. The distance between the top of the ridge and the furrow's bottom is kept at 20 to 25 cm. A few days prior to

planting, the ridges and furrows are constructed. A few days prior to planting, the ridges and furrows are constructed. To create a healthy seed bed, the bottoms of the furrows are loosened to a depth of around 10 cm. Channels for drainage and irrigation should be properly supplied. At a distance of 20 to 25 metres from the furrows, irrigation channels are installed (Lal and Singh, 2007). In order to lift irrigation, the distance might be lowered. If the field is level and not graded in one direction, an irrigation channel can be used to water the furrows on each side. In these situations, the irrigation water is diverted to irrigate the furrows on either side, and a small bund across the furrow is required to check flow at regular intervals. In heavily watered areas, drainage systems are crucial Before planting sugarcane, cross channels are created to help with monsoon water drainage.



IISR 86206 Method of Planting

The IISR 86206 technology developed at IISR Lucknow could improve cane production in north Indian settings (Van,1952). The IISR 86206 technique of cane planting entails ditches filled with "long" or "tailed" rayungans, which are about 40 cm long sugarcane top setts with several nodes and side shoots at the top. The various digits in the number 86206 stand for a code for a planting method variant with five heads, as shown in the Table-2. The term CAEGUS, which stands for "Consociation of auxin action, extension of growth, and unrestricted usage of soil," is also used to refer to the approach. About 30 days prior to the planned planting date, the crop that is standing in the field for seed purposes is topped. The side branches are permitted to reach the stage of 3–4 leaves. There are 90 cm-apart ditches that are about 20 cm wide and 45 cm deep. Just before planting, after being mixed with the necessary amount of fertilizer, the soil that has been built up in the interspaces is placed back into the trench. Light irrigation is used to allow water to sink into the trench's soil. The green leaves of the cane shoots are trimmed, and rayungans are cut from the stalk. With the bases of the side shoots about 5–10 cm below the original soil surface, the "tailed" rayungans are then driven vertically into the damp soil to maintain their upright position.The total number of tailed rayungans required per hectare is approximately 15,000-20,000 per hectare. The distance between the rayungans should be kept between 50–75 cm. To ensure higher net returns and farm efficiency, the remaining pieces of the cane stalk are used as seed cane for conventional planting. This approach has a faster rate of cane crop growth than the standard flat planting. The cost per unit of cane production is significantly reduced (by 30%) as a result of the astonishingly greater cane yields (150-200 t/ha) that are achieved. Additionally, ratoon yields are higher (Solomon and Sharma, 2014).

Improved method of sugarcane planting Ring-pit method

Ring-pit method

Tillers in sugarcane crop start emerging after about 45 to 60 days of the emergence of the mother shoots, so these remain comparatively weak and develop into millable canes of lesser length, girth and weight. To accommodate more numbers of mother shoots in the same place, tillers need to be suppressed. Hence, more number of setts are planted in circular pitts at relatively greater depth and the mother shoots are allowed to grow with very less or no tillers. This method is called as ‘Ring – pit planting’ because sugarcane is planted in pits of circular shape. This technology is also called ‘No tiller technology’ or ‘Mother shoot technology’.

The ring or pit system of planting developed by the Indian Institute of Sugarcane Research, Lucknow

(Singh *et al.*, 1984) has huge potential to increase yields. In the system, circular pits of 90 cm diameter are dug out to a depth of 45 cm with a gap of 60 cm between the two adjacent pits. At this spacing, the pits are spaced at 150 cm apart. The layout was modified with a gap of 60 cm on one side and 90 cm on another side in which the irrigation channel was formed (Sundara, 1994 and 1998). The pits are filled with loose soil and FYM or pressmud to a depth of 15 cm, twenty-two-bud setts are planted in each pit, and covered with soil to a thickness of 5 cm. As the crop grows, the dugout soil is reapplied to the pits at the time of manuring. This system has given 100% more yield as compared to the normal planting in the subtropics (Yadav and Singh, 1987).

The dugout soil is kept on the periphery of each pit. Twenty pieces of 2-budded treated setts are placed in each pit in a similar pattern as of spokes in a cycle wheel. *Trichoderma* 20 kg mixed with 200 kg of FYM or press mud per hectare is applied over the setts. The recommended dose of fertilizers are applied. The pits are filled with the dugout soil up to 5 to 7 cm depth at 4^{th} leaf stage(50 – 55 days after planting in autumn and 40 – 45 days after planting in spring).This technology is suitable for drought prone areas, undulating topography, light textured soils, saline - sodic soils, multiple ratooning and high yielding, tall and thick cane varieties. By this method, cane yield is increased by 1.5 – 2.0 times (up to 125 t/ha) and irrigation water is saved up to 30 – 40 per cent. Water use efficiency is increased by 30 – 40 per cent and nutrient use efficiency by 30 – 35 per cent. The technology also results more ratoons (3-4 ratoons) and higher sugar recovery (by 0.5 unit) resulting in higher profit to farmers. Lodging and uprooting of clumps is also reduced due to deeper planting. The benefit – cost ratio in sugarcane farming by adopting this method is 1.83. The advantages of adoption of Ring pit method, the sugarcane productivity is increased by 30-40 per cent as compared to the conventional method (Yadav, 2007). In this method, only the pits are irrigated and the space between two rows is not irrigated, resulting in saving of 30-40 percent of irrigation water. Due to the use of nutrients in the pit, the efficiency of utilization of nutrients increases by 30-35 percent, due to which the yield of sugarcane is also obtained. Due to deep planting, the problem of falling of sugarcane along with the root at the spot is also solved.

Spaced Transplanting Technique

In conventional planting of sugarcane using three bud setts, genetic potential for tillering is not fully exploited. Inter-plant competition and unevenly distributed solar radiation tend to affect tillering. Occurrence of higher mortality, adversely affected stalk density and crop productivity, per *se*. In addition, transportation of bulk seed material and slow multiplication rate (ratio being 1:8 to 1:10) are important constraints for the seed multiplication programme. Based on the sound physiological understanding of germination (sprouting), tillering *vis-a-vis* inter and intra-plant competition, a scientific crop management procedure, the Spaced Transplanting Technique (STP) has been developed for synchronization of tillering and quick seed multiplication of sugarcane. This technique ensures higher stalk population (number of millable canes) with a uniform crop stand and higher average cane weight. In this technique, a nursery is raised in small area nearly a month before the actual transplanting, preferably near the field to be transplanted. Land is prepared to a depth of 15 cm and small plots (1 sq.m) are made. Before dibbling setts, chorpyriphos @ 1 kg a.i. /ha is applied. Single buds setts (from upper half of the cane) are cut just above the growth ring and leaving 9-10 cm of the internode below the bud followed by dipping for 30 min in 0.2% Carbendazim (Bavistin). The setts are dibbed vertically (600 – 800 setts/sq.m) in the irrigated nursery. Trash and paddy straw is spread over the setts and then mulched with pulverized soil. Most of the buds sprout and in 3 – 4 weeks, produce 3 – 4 green leaves. Settlings are carefully removed and leaf laminae detopped. These are dipped in 0.2 % Carbendazim (Bavistin) suspension for 30 min. Transplanting of settlings is done in trench or flat system, in rows with 90 x 60 cm spacing (19,000 settlings) or 75 x 45 cm spacing (29,000 settlings). Settlings are dibbed and covered with soil leaving at least 5 cm of the shoot above the ground level, followed by an immediate lifesaving irrigation. After 10 days of transplantation, the gaps, if any, are filled by the nursery kept in reserve. Normally, 5 – 10% mortality takes place. This technique is a boon for rapid multiplication of seed cane. The STP technique is very useful for rapid seed cane multiplication. It is highly effective in saving seed cane to the tune of 4 t/ha. It maintains relatively higher population of millable canes (>1.2 lakh canes/ha). It improves the ratio of seed cane to output from 1:10 to 1:40. Ratoon of a (preceding) plant crop raised from STP gives higher cane yield (Shrivastava and Rai, 2007).

Mechanized trench method

The germination of sugarcane is limited up to 30% due to the flat method's reduced irrigation. The trench approach is especially helpful when there is no irrigation. After planting, sugarcane germination in the trench method is rather high. To plant sugarcane using the trench method, create trenches that are 20 cm deep and 40 cm broad, keeping the center of each trench and the other parallel trench 90 cm apart. After adding compost prepared from cow dung or pressed manure, carefully combining it, and then covering the trenches with 4-5 cm of soil, three-eyed pieces of sugarcane are planted in them.

Sugarcane planting by mechanized trench method

the trenches and after few days, a blind hoeing is done, which results in good germination. After the germination of sugarcane, according to the growth of the crop, soil is put in the trenches, by doing this, a ridge is formed in place of a trench and a trench in place of a ridge which is used for drainage during the rainy season. By this method, along with good yield of planted sugarcane, the good yield of ratoon crop is also obtained. In this method, up to 70-75 per cent germination is achieved.

In this method, one or one and a half month before planting, about 25 cm deep trenches are made for winter sugarcane at an interval of 90 cm and for spring sugarcane at 75 cm interval. Cow dung or pressed manure of sugar mill is applied @ 5-10 tonne per hectare in this prepared trench. The soil is prepared well by pouring irrigation and hoeing. After the sugarcane germination, along with the gradual growth of the crop, the soil of the ridges is dropped on the roots of the plants in the trench, which eventually forms a ridge in place of the trench and a trench in place of the ridge, which along with the irrigation trench, gets water during the rainy season. Also performs the function of drainage. This method is suitable for loamy land with high compost level and abundant input availability. This method not only gives a higher yield, but at the same time, the consumption capacity of irrigation water and nutrients also increases (Lal and Singh, 2007).

Paired row method

Sugarcane planting by paired row

In this method, at the interval of 90:30:90 or 120:30:120 or 150:30:150 cm, about 10 cm deep furrows are prepared in the field. In this method, the quantity of setts can be increased from normal to less than normal on the basis of rows and this method is suitable for more fertile cultivation in availability of abundant manure and water (Lal and Singh, 2007). This method gives higher yield of sugarcane. By adopting paired row method, farmers can harvest more sugarcane yield as well as earn more profit by adopting companion cropping. By adopting this method and by promoting mechanization in sugarcane farming, cultivation can be done successfully even in the case of labour scarcity.

Planting with manually fed sugarcane cutter planters

FIRB (Furrow Irrigated Raised Bed) method

Generally, the planting of sugarcane is done in two- to three-eyed setts in the cut-out cistern, 60-80 quintals per hectare is required for planting sugarcane by this method. Time and labour are also spent in harvesting, transporting, cutting setts, planting etc. Due to excessive weight, farmers are not able to treat sugarcane effectively, due to which effective control of seed borne diseases is not achieved. Seed cane minimization techniques like STP, single bud planting, single bud seed or bud chip seedling, sowing of seedlings prepared by tissue culture method for higher yield per unit and for setting up micro irrigation unit *etc.* can be used. Among the methods described above, single bud seedlings or bud-chip seedlings are gaining popularity. Planting of sugarcane by preparing seedlings by this method can save about 80 percent of sugarcane seed. Therefore, this technology is another option for farmers to earn more profit by reducing the cost. In this method, the sugarcane bud should be removed and prepared in the nursery and the rest of the process should be done like poly bag or cane node method (Solomon and Sharma, 2014).

Bud-chip Sowing Technique

Poly bag method

Polybag method is also very effective in the case of shortage of seeds of improved varieties. By this method, 18-20 quintals of sugarcane is required per hectare. For prepare the nursery, the upper 2/3 part of the sugarcane is cut into pieces with one eye, their cut pieces are immersed in 5 litres of water by mixing 100 grams of Bavistin for 15-20 minutes. After this, the cut treated pieces are kept in a polythene bag in a vertical position in such a way that the eyes are facing upwards, after that 2-3 cm layer of soil is laid over it and a light irrigation is given. Spraying of water 2-3 times at an interval of 5-6 days in poly bag nursery. In three to four weeks, a good set is achieved, and 3-4 leaves are produced, which are about 6 inches in length. The upper leaves of the plants should be cut by 2-3 cm before transplanting. By doing this, the loss of water by the plants is reduced. In the prepared field in which these plants are to be transplanted, a furrow is made by the ridge at a distance of 90 cm and plants should be transplanted at a distance of 45 cm in these furrows. Thus, about 23,500 plants are planted in one hectare. Irrigation should be done immediately after transplanting. After 8-10 days after transplanting, inspect the field, if the plants have dried up or died at any place, then new plants should be transplanted again at that place (Singh and Prasad, 2007).

3. Conclusion

In India's agrarian economy, sugarcane plays a significant role and provides support to one of the biggest agro processing sectors in the nation. In addition, the sugar sector employs over 500,000 skilled and semi-skilled employees, most of whom come from rural areas. India will

need close to 33 million tonnes of white sugar by the year 2030 just for domestic use. It is clear that improving crop productivity and quality will be essential to achieving the future sugarcane output objective.

Sugarcane germination as well as yield is affected by planting material, layout, plant- population, method of planting and placement of bud etc. Whole cane, setts having of single bud to six buds, settling prepared from tissue culture or single eye buds in nursery are used as planting material for sugarcane propagation. Sett planting method is mostly followed commercially through flat planting, ridges and furrows or ring pit method. The researchers found that the sett having two eye buds are giving germination about 65 to 70 % with better yield. Large setts have better survival under bad weather but single budded setts also give 70% germination if protected with chemical treatment.

In India, the mechanisation of sugarcane farming has not yet been fully utilised. For sugarcane cultivation, traditional tools and equipment are still widely used. One of the causes of the low level of mechanisation is holding size. Without a doubt, mechanisation will increase sugarcane production's profitability while also lowering labour-intensive tasks that humans must perform. To increase the use of equipment based on sugarcane cultivation, various organisations, including the sugar industry, state agricultural universities, research organisations, cane departments, etc., must coordinate their efforts (Singh and Sharma 2010).

The next phase of revolution in Indian agriculture is bound to come through the use of improved cultivation practices suiting to local conditions. Concerted efforts are required to formulate a strategy for improved cultivation techniques and mechanising sugarcane production in India with the sole aim of increasing production and productivity per unit time, area and input at reduced cost of unit operation. This is must if we have to survive in the highly competitive international sugar market.

References

- DAC. 2020. Pocket book of agricultural statistics.
- Deshmukh, A. S., Shinde P.P., Gaikwad R.N., Nelekar D.S. and Shinde S.H. 2009. Performance evaluation of VSI developed mechanical sugarcane planter, *Proceedings of 70th Annual Convention of Sugar Technologist Association of India*, pp. 46-47.
- FAOSTAT (Food and Agriculture Organization of the United Nations). 2018. Statistics database. [cited 2018 Feb 2] http://www.fao.org/faostat/en/#data.
- Hemalatha S. 2015. Impact of nitrogen fertilization on quality of sugarcane under fertigation. *International Journal of Research and Scientific Innovation.* 2(3): 37-39.
- Kamini Singh, Lal Singh Gangwar, 2023. Planting Techniques in Sugarcane Cultivation: A Review. *International Journal of Agricultural Science, Volume 8, 357-370.*
- Khedkar, M.B. and Kamble A.K. 2008. Evaluation of mechanized planting of sugarcane. *International Journal of Agricultural Engineering*, Vol. 1 No. 2: 136-13.
- Lal M, Singh I. 2007. Conventional methods of sugarcane planting and their Improvement. In: Yadav RL, Yadav DV, editors. Sugarcane planting Techniques and Crop Management. ICAR-Indian Institute of Sugarcane Research Lucknow. p.1-6.
- Mao L, Que F, Wang G. 2006. Sugar metabolism and involvement of enzymes in sugarcane (*Saccharumofficinarum* L.) *stems during storage. Food Chemistry*. 98(2): 338-342.
- S. M. Nalawade[1], A. K. Mehta[2] and A. K. Sharma[3], 2018. Sugarcane Planting Techniques: A Review. National Seminar "*Recent Trends in Plant Sciences and Agricultural Research (PSAR- Jan., 2018)* 90-104.
- Shrivastava AK, Rai RK. 2007. Spaced Transplanting Technique. In: Yadav RL, Yadav DV, editors. Sugarcane planting Techniques and Crop Management. ICAR-Indian Institute of Sugarcane Research Lucknow. p. 7-9.
- Shrivastava AK, Rai RK.2007. Spaced Transplanting Technique. In: Yadav RL, Yadav DV, editors. Sugarcane planting Techniques and Crop Management. ICAR-Indian Institute of Sugarcane Research Lucknow. p. 7-9.
- Shukla SK, Sharma L, Awasthi SK, Pathak AD.2017. Sugarcane in India: Package of Practices for Different Agroclimatic Zones. p. 1-64.
- Singh SN, Prasad SR. 2007. Polybag Technology of Sugarcane Planting. In: Yadav RL, Yadav DV, editors. Sugarcane planting Techniques and Crop Management. ICAR-Indian Institute of Sugarcane Research Lucknow. p. 11-15.
- Solomon S, Sharma AK, Shukla SK. 2014. Technorama. ICAR-Indian Institute of Sugarcane Research Lucknow. p. 60.
- Sundara B. 2007. Wide row spacing planting of sugarcane. In: Yadav RL, Yadav DV, editors. Sugarcane planting Techniques and Crop Management. ICAR-Indian Institute of Sugarcane Research Lucknow. p. 29-36.
- Van DC. 1952. Botany of sugarcane, Elsevier, New York, Amsterdam, 409-438.

Just Agriculture Multidisciplinary e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

D. Kanjana
Senior Scientist (Soil Science)
Central Institute for Cotton Research (ICAR), Regional Station, Coimbatore

R. Raja
Principal Scientist (Agronomy)
Central Institute for Cotton Research (ICAR), Regional Station, Coimbatore

A. Basith
Young professional
Central Institute for Cotton Research (ICAR), Regional Station, Coimbatore

ARTICLE ID: 24

Regenerative Agriculture: Restoring Soil Health for Climate-Resilient and Profitable Farming

Introduction

Regenerative Agriculture (RA) is a holistic approach that emphasizes the health of soil, plants, animals, humans, and the environment as an interconnected and inseparable system. The term was coined by Robert Rodale in the 1980s to distinguish it from sustainable agriculture. However, it gained significant attention around 2018 as a soil-centric approach, focusing on restoring, rebuilding, and regenerating soil health. Conventional farming practices primarily aim to maximize yields through the indiscriminate use of synthetic inputs such as fertilizers, pesticides, and other agrochemicals. While this approach may enhance short-term productivity, it often disrupts soil ecosystems and reduces biodiversity. In contrast, regenerative agriculture promotes the concept of achieving optimum and sustainable yields with fewer resources, including land, water, energy, and external inputs.

Regenerative vs Conventional and Conservation Agriculture

Regenerative agriculture shares several practices with conservation agriculture, such as minimal or no tillage, cover cropping or mulching, and crop rotation or diversification. However, key differences exist. In regenerative systems, greater emphasis is placed on organic nutrient sources like compost and biochar, whereas conservation agriculture relies on integrated nutrient and pest management, combining both organic and inorganic inputs. Additionally, regenerative agriculture incorporates livestock integration and agroforestry, which are generally absent in conservation agriculture systems. While both approaches aim to improve soil health through soil organic carbon sequestration, conservation agriculture focuses on maintaining and conserving soil health, whereas regenerative agriculture seeks to restore, rejuvenate, and revitalize degraded soils (Table 1).

Table 1. Comparison of Farming Systems: Conventional vs Conservation vs Regenerative

Main Goal	**High yield (short-term)**	**Soil conservation**	**Soil restoration & resilience**
Tillage	Intensive	Minimum	Minimum/No-till
Nutrient Source	Mostly chemical	Integrated (organic + inorganic)	Mostly organic (compost, biochar)
Crop System	Monocropping	Crop rotation	Diversification + cover crops
Soil Organic Carbon	Declining	Maintained	Increased
Biodiversity	Low	Moderate	High
Livestock Integration	Rare	Limited	Important component
Agroforestry	Absent	Rare	Common
Climate Impact	High emissions	Moderate	Low emissions (carbon sink)
Sustainability	Low	Moderate	High

Regenerative Agriculture, Organic Farming, and Natural Farming

Regenerative agriculture shares similarities with organic farming but differs in its focus. Organic farming strictly prohibits synthetic agrochemicals and genetically modified organisms (GMOs) and follows defined standards and certification systems. In contrast, regenerative agriculture is outcome-oriented, prioritizing improvements in soil health and ecosystem function. It may allow limited use of chemicals during the transition phase and currently lacks standardized certification. Organic farming is largely process-driven, whereas regenerative agriculture is result-driven, aiming to rebuild degraded soils, enhance soil organic matter, and strengthen biogeochemical cycles of carbon and nutrients. This has led to the emerging concept of Regenerative Organic Agriculture (ROA), which integrates the strengths of both systems.

Similarly, natural farming emphasizes the use of locally available resources and eliminates external inputs altogether. Despite differences in approach, all these systems share a common goal: improving soil organic matter, enhancing biodiversity, and sustaining soil health.

Regenerative Agriculture in India

In India, regenerative agriculture has the potential to transform farming systems by reducing greenhouse gas (GHG) emissions, sequestering atmospheric carbon, and improving soil health. Practices such as reduced tillage, cover cropping, crop diversification, organic amendments, livestock integration, agroforestry, and perennial systems contribute to building resilient agricultural systems (Fig 1).

- **Mitigating climate change**

  The agricultural sector in India accounts for approximately 19% of total GHG emissions, arising from activities such as enteric fermentation (54.6 %), fertilizer use (19.1 %), rice cultivation (17.5 %), manure management (6.6 %) and crop residue burning (2.2 %) (Nikita, 2023). Regenerative agriculture offers a sustainable pathway to mitigate these emissions while maintaining productivity.

- **Restoring degraded soils**

  About 30% of India's land area is affected by soil degradation due to erosion, salinity, acidity, and poor management practices. Regenerative agriculture offers an effective solution by restoring topsoil, improving water holding capacity, maintaining soil fertility, reviving biodiversity, and enhancing long-term productivity, especially in degraded regions.

- **Building soil resilience to drought and waterlogging**

  Healthy soils can hold 20-30 % more water by reducing evaporation losses, increasing water retention capacity, enhancing infiltration rate, accessing the deeper soil moisture and reducing surface runoff during heavy rains while adopting the regenerative practices such as cover cropping, agroforestry and deep rooted perennial legumes. Therefore, farms become more resilient against droughts by storing more moisture and **manage waterlogging** by allowing excess water to drain more effectively (Akhil et al. 2025).

- **Expanding carbon credit as a source of income**

  Regenerative practices can reduce the greenhouse gas emissions, combat the climate change and sequester the carbon in soil. Farmers can sequester 1 to 4 tonnes of CO_2 on 1 hectare of land by adopting regenerative practices which fetch an income of Rs. 1500 to 5000 (USD 15 to 50 per tonne of sequestered carbon) from carbon market which could be a significant source of income to the farmers. With the help of regenagri certification, cotton growing farmers of Vidarbha district (Maharashtra) achieved 20-30 per cent of increased seed cotton yield with 30 percent reduced input cost by adopting regenerative agriculture practices (www.orfonline.org)

How Regenerative Practices Improve Soil Health

Core practices of regenerative agriculture play a crucial role in enhancing soil health and carbon sequestration:

- **Minimum tillage** reduces soil disturbance and prevents rapid oxidation of soil organic carbon,

Fig 1. Pathway to climate resilient and profitable farming

- helping stabilize it within soil aggregates. It also preserves beneficial fungal networks such as
- arbuscular mycorrhizae.
- **Cover crops** (legumes, grasses, brassicas) protect soil from erosion, improve water infiltration, regulate temperature, and enhance microbial activity. Legumes also contribute through biological nitrogen fixation.
- **Crop rotation and diversification** support diverse microbial communities, improving nutrient cycling and soil structure.
- **Organic amendments** like compost, farmyard manure, crop residues, green manure, and biochar enhance soil organic carbon through physical protection and chemical stabilization.
- **Crop–livestock integration** improves nutrient recycling and soil biological activity.
- **Agroforestry systems** contribute to long-term carbon storage, particularly in deeper soil layers.

Policy Support and Initiatives

The Government of India has recognized the importance of sustainable agriculture and promotes eco-friendly practices by reducing synthetic fertilizer/pesticide use and improving soil carbon through initiatives such as the Paramparagat Krishi Vikas Yojana (PKVY) or National Mission on Natural Farming (NMNF). Research and awareness efforts are also sup

ported by the Indian Council of Agricultural Research. Additionally, private sector organizations are encouraging farmers to adopt regenerative practices.

Challenges in Adoption

Despite its potential, several challenges limit the widespread adoption of regenerative agriculture:

- Concerns about reduced tillage, including soil crusting and poor infiltration
- Preference for short-term yield gains over long-term sustainability
- Delayed benefits of regenerative practices
- Higher initial investment compared to immediate returns
- Fertilizer subsidies discouraging reduced chemical use
- Lack of clear policies, standards, and certification systems
- Need for better coordination and large-scale implementation

Conclusion

Regenerative agriculture represents a shift from input-intensive farming to a nature-based, resilient system. By restoring soil health, enhancing biodiversity, and improving nutrient cycling, it offers a sustainable pathway for future agriculture. Adopting regenerative agriculture in India can play a crucial role in achieving food security, environmental sustainability, and climate resilience, making it a vital approach for the future of farming.

References

- Akhil, K., Renukaswamy N. S, Venugopala K. M, Jakkampudi Sowjanya, Kishore S.M, and Bharthisha S.M. 2025. "Revitalizing Soil Health through Regenerative Agriculture: History, Principles, Practices and Challenges". International Journal of Environment and Climate Change 15 (8):249-62. https://doi.org/10.9734/ijecc/2025/v15i84969.Nikita, R. 2023. Green House Gas Emissions from Paddy Field. Just Agriculture – a multidisciplinary newsletter. Vol. 3 Issue-12, August 2023 (e-ISSN: 2582-8223)
- https://www.orfonline.org/expert-speak/regenerative agriculture

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

ARTICLE ID: 25

Plant Stress Challenges and the Emerging Role of Integrated Omics in Crop Improvement

AUTHORS' DETAILS:

Ritu Siwach
Department of Agricultural Biotechnology and Molecular Biology, Dr. Rajendra Prasad Central Agricultural University, Pusa-848125, Bihar, India.

Kumari Anjani
Department of Agricultural Biotechnology and Molecular Biology, Dr. Rajendra Prasad Central Agricultural University, Pusa-848125, Bihar, India.

Bishun Deo Prasad
Department of Agricultural Biotechnology and Molecular Biology, Dr. Rajendra Prasad Central Agricultural University, Pusa-848125, Bihar, India.

Vinay Kumar Sharma
Department of Agricultural Biotechnology and Molecular Biology, Dr. Rajendra Prasad Central Agricultural University, Pusa-848125, Bihar, India.

Abstract
Plants are subjected to various abiotic stresses, including drought, salinity and extreme temperatures, as well as biotic stresses from pathogens and pests. Climate change has intensified these challenges, threatening global crop productivity and food security. Understanding the molecular mechanisms that enable plants to survive and adapt to stressful environments has become a key focus of plant research. Integrated multi-omics approaches encompassing genomics, transcriptomics, proteomics and metabolomics provide a comprehensive platform for elucidating stress-response networks and identifying key molecular mechanisms underlying resilience. The advancement of RNA sequencing, LCMS based platforms, high-throughput phenotyping systems and genome-editing tools such as CRISPR/Cas9 has enhanced the ability to investigate plant responses at the molecular and cellular levels.
Emerging fields such as single-cell and spatial omics, regulatory RNA studies, stress memory and plant microbiome interactions provide deeper insights into plant resilience under environmental conditions. Combined with systems biology and big data analytics, these approaches support precision breeding strategies to improve crop performance. The integration of multi-omics technologies offers a framework for understanding plant stress tolerance and developing climate resilient crop varieties for sustainable agriculture.
Keywords: abiotic stress and biotic stress, CRISPR-Cas9, multi-omics integration, precision breeding

INTRODUCTION

Plants are constantly challenged by abiotic stresses like drought, salinity and extreme temperatures, as well as, biotic factors, such as, pathogens and pests. The escalating global population, climate change and depleting resources demand urgent and sustainable advancements in agriculture. Climate change has intensified the frequency and severity of abiotic and biotic stresses, posing a major threat to global crop productivity and food security (Presti et al.,2023). With the global population expected to reach 10 billion by 2050, enhancing crop productivity is critical to ensure food security. Genetic improvement through crop breeding remains one of the most effective strategies. However, despite the availability of whole-genome sequences and functional annotations, much of the genomic data remains underutilized, particularly in understanding complex gene interactions related to stress resilience (Naik et al., 2024). Therefore, there is an urgent need for advanced, automated and accurate technological platforms that can comprehensively capture and integrate multi-omics data with genomic and phenotypic information throughout all stages of plant development to effectively address the existing gap. This integration offers a strong foundation for understanding how plants respond to abiotic and biotic stresses at various molecular levels (Gupta et al., 2023).

For instance, a genome-wide analysis in cucumber identified six Group III WRKY transcription factors, highlighting their critical roles in regulating plant growth, development and stress responses (Xia et al., 2025). Similarly, sub-cellular organelles like peroxisomes have been shown to enhance abiotic stress tolerance by acting as alternative energy sources under stress conditions, as demonstrated in *Vigna radiata* (Saha et al., 2024). Among the major abiotic stresses, salinity severely hampers plant growth by causing osmotic and ionic imbalances. Plants counter these effects through mechanisms such as ion homeostasis, osmotic adjustment and activation of antioxidant defenses. In this context, Zhang et al. (2023) reported that over-expression of the *BvNHX1* gene from sugarbeet in tobacco improved salt tolerance by enhancing germination, promoting growth and maintaining a favourable K^+/Na^+ balance. These studies collectively underscore the potential of multi-omics and molecular approaches in identifying key genetic and physiological determinants of stress resilience in plants. Transcriptomic analysis of drought-tolerant and sensitive rice cultivars revealed elevated expression of stress-responsive genes such as *OsNAC10*, *OsbZIP23* and *OsABA8ox1* in the tolerant variety. These genes contribute to drought tolerance by modulating transcriptional control, redox homeostasis and ABA signaling pathways (Tyagi et al., 2023). Beyond abiotic stress, transcriptomics also offers promising strategies for disease management, providing sustainable alternatives to conventional pesticides, which are often costly and environmentally harmful. Emerging RNA interference (RNAi) technologies, including the exogenous application of double-stranded RNA (dsRNA), have shown potential as eco-friendly crop protection tools (Srimahesvari et al., 2024). RNA sequencing (RNA-seq) plays a pivotal role in unravelling host-pathogen interactions and has been utilized to investigate the molecular response of *Gardenia jasminoides* to *Botryosphaeria dothidea* infection (Zhou et al., 2023). Furthermore, public RNA-seq datasets support ongoing research efforts; for example, Chauhan et al. (2024) identified circular RNAs associated with stripe rust resistance, highlighting the utility of transcriptomic data in understanding and improving plant defense mechanisms. Building on these molecular insights, recent advancements in high-throughput phenotyping have greatly improved the understanding of plant physiological responses to stress. Cutting-edge tools such as imaging systems, robotics and sensor-based technologies enable accurate, non-invasive monitoring of plant traits, thereby supporting the effective identification and selection of stress-tolerant genotypes (Anand et al., 2024; Pandey et al., 2024**).** These emerging areas provide novel insights into the complex regulatory networks underlying plant adaptation and resilience under multi-factorial stress conditions. When combined with advanced tools such as genome editing and big data analytics, integrated omics approaches are paving the way for precision breeding strategies (Varadharajan et al.,2025). This convergence underscores the growing relevance of systems biology in addressing the challenges of sustainable agriculture. Overall, integrated omics offers a promising framework to decode plant stress tolerance mechanisms and guide the development of robust cultivars capable of thriving under increasingly unpredictable climatic conditions (Gupta et al., 2023).

OBJECTIVE

The objective of this study is to explore various omics approaches and their sub-disciplines for investigating plant stress responses at both the molecular and genetic levels. By integrating insights from multi-omics techniques, the study seeks to develop a holistic understanding of the mechanisms underlying plant resilience. This comprehensive knowledge will effectively contribute to formulate more effective strategies for enhancing crop stress tolerance, particularly in the context of a changing climate.

METHODOLOGY

The reviewed literature compiles and evaluates existing studies utilizing diverse multi-omics approaches such as genomics, transcriptomics, proteomics, metabolomics, ionomics and phenomics to investigate plant stress responses at molecular and physiological levels. Key technologies include RNA-seq, LC-MS, NMR and 2D gel electrophoresis for profiling gene expression, proteins and metabolites (Varadharajan et al.,2025). High-throughput phenotyping, genome editing tools like CRISPR/Cas9 and next-generation sequencing are used for identifying stress-related genes (Naik et al.,2023). Bioinformatics platforms such as PRIDE, Cytoscape Web and PathwayMatrix aid in data integration and functional analysis (Gupta et al., 2023).

RESULTS

Current research emphasizes that omics approaches, though sometimes invasive, are highly sensitive and effective in detecting plant responses to various stresses. Technological advances have broadened their application, allowing in-depth analysis of molecular and cellular mechanisms involved in stress adaptation. Notably, numerous stress-responsive genes and pathways have been identified, which help to maintain ion homeostasis and alter amino acid metabolism under salt stress. Studies also reveal that changes in gene, protein and metabolite expression are both stress-specific and species-dependent. The differential expression of miRNAs under different stress conditions highlights their regulatory role in modulating gene expression and enhancing stress tolerance. The integration of multi-omics layers such as transcriptomics, proteomics and metabolomics provides a systems-level understanding of plant stress responses. Emerging genome editing tools like CRISPR/Cas9 offer new opportunities for developing stress-resilient crops through targeted genetic improvements. These approaches facilitate the identification of key stress-responsive genes, regulatory pathways, transcriptional networks and molecular markers essential for developing resilient crop varieties.

CONCLUSION

Precise integration of multiple omics approaches is crucial for unravelling plant responses to abiotic and biotic stress at molecular, genetic and physiological levels. By combining genomics, transcriptomics, proteomics, metabolomics and phenomics, researchers can identify key genes, regulatory networks and stress-responsive pathways. Advanced tools, such as next-generation sequencing and CRISPR/Cas9, enable the precise manipulation of these pathways to enhance stress tolerance. This integrated strategy holds great promise for improving crop productivity and ensuring food security in the face of global climate change.

REFRENCES

- Anand, S., L. Visakh, R., Nalishma, R., Sah, R. P., & Beena, R. (2025). High throughput phenomics in elucidating drought stress responses in rice (*Oryza sativa L.*). *Journal of Plant Biochemistry and Biotechnology*, *34*(1), 119-132.
- Chauhan, D., Mishra, D. C., Balley, P., Bhati, J., Pandey, H., & Khan, S. (2024). Emphasizing the role of wheat circular RNA in defense response against stripe rust disease. *Journal of Plant Biochemistry and Biotechnology*, 1-12.
- Gupta, S., Kaur, R., Sharma, T., Bhardwaj, A., Sharma, S., Sohal, J. S., & Singh, S. V. (2023). Multi-omics approaches for understanding stressor-induced physiological changes in plants: An updated overview. *Physiological and Molecular Plant Pathology*, *126*, 102047.
- Naik, B., Kumar, V., Rizwanuddin, S., Chauhan, M., Choudhary, M., Gupta, A. K., ... & Rustagi, S. (2023). Genomics, proteomics, and metabolomics approaches to improve abiotic stress tolerance in tomato plant. *International Journal of Molecular Sciences*, *24*(3), 3025.
- Naik, Y. D., Zhao, C., Channale, S., Nayak, S. N., Bhutia, K. L., Gautam, A., ... & Thudi, M. (2024). Bioinformatics for plant genetics and breeding research. In *Frontier Technologies for Crop Improvement* (pp. 35-64). Singapore: Springer Nature Singapore.
- Pandey, H., Sharma, R., Thakur, D. S., Rana, M., & Sharma, P. (2025). Simple sequence repeats (SSRs)-based characterization of cultivated and indigenous wild pomegranates (*Punica granatum L.*) revealed evolutionary relationships with considerable insights to native resource exploration: SSR Markers revealed narrow genetic base in pomegranate. *Journal of Plant Biochemistry and Biotechnology*, *34*(1), 344-348.
- Presti, D. L., Di Tocco, J., Massaroni, C., Cimini, S., De Gara, L., Singh, S., ... & Cinti, S. (2023). Current understanding, challenges and perspective on portable systems applied to plant monitoring and precision agriculture. *Biosensors and Bioelectronics*, *222*, 115005.

- Saha, S., Samanta, I., Tarafdar, S., Mishra, S., & Chowdhary, G. (2024). Predicting the peroxisome proteome in the legume Vigna radiata: exploring peroxisomal roles in abiotic stress tolerance. *Journal of Plant Biochemistry and Biotechnology*, 1-18.
- Srimahesvari, D. S., Harish, S., Karthikeyan, G., Kannan, M., & Kumar, K. K. (2024). Advancements in dsRNA-based approaches: a comprehensive review on potent strategies for plant disease management. *Journal of Plant Biochemistry and Biotechnology*, 1-19.
- Tyagi, A., Kumar, S., & Mohapatra, T. (2023). Biochemical, physiological and molecular responses of rice to terminal drought stress: transcriptome profiling of leaf and root reveals the key stress-responsive genes. *Journal of Plant Biochemistry and Biotechnology*, 1-20.
- Varadharajan, V., Rajendran, R., Muthuramalingam, P., Runthala, A., Madhesh, V., Swaminathan, G., ... & Ramesh, M. (2025). Multi-Omics Approaches Against Abiotic and Biotic Stress.A Review. *Plants*, *14*(6), 865.
- Xia, K., Zhou, Z., Hu, Y., Wang, Y., Hu, Z., Zhou, Y., ... & Zhou, Y. (2025). Identification of the group III WRKY subfamily and preliminary functional characterization of CsWRKY59 in cucumber. *Journal of Plant Biochemistry and Biotechnology*, 1-13.
- Zhang, X. M., Wu, G. Q., Wei, M., & Kang, H. X. (2023). Overexpression of BvNHX1, a novel tonoplast Na+/H+ antiporter gene from sugar beet *(Beta vulgaris*), confers enhanced salt tolerance in transgenic tobacco. *Journal of Plant Biochemistry and Biotechnology*, 1-13.
- Zhou, L., Zhang, C., Zhou, Q., Liao, M., Feng, Z., Zhu, P., ... & Luo, G. (2023). Transcriptome analysis of Gardenia jasminoides Ellis in response to Botryosphaeria dothidea. *Journal of Plant Biochemistry and Biotechnology*, 1-12.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Manoj Kumar Prajapati

Assistant professor Faculty of Agriculture and allied Science, United University, Jhalwa Rawatpur, Prayagraj (U.P.)

Govind Vishwakarma

Department of Soil Science, Post-Graduate College of Agriculture, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur-848125, (Bihar)

Sandip Kumar Gupta

Department of Soil Science and Agricultural Chemistry, Shri Murli Manohar Town P.G. College, Ballia-277001 (Affiliated to Jananayak Chandrashekhar University, Ballia, (U.P.)

ARTICLE ID: 26

A Tailored Approach Towards Seed Biopriming in Sustainable Agriculture

Abstract

Seed play a crucial role in agriculture and circulated at large scale in international trade. However, many plant pathogens can be seed-borne and transmitted through seed and distribution of seeds is extremely capable way of introducing the plant pathogens in new areas. In past decades, chemicals are widely used for seed treatment as a potent approach towards disease control. However, rising concern about their negative impact on the environment and human health minimizes their use and promotes biological control for plant pathogens. Biopriming is a most reliable, vital, economical, and eco-friendly approach of seed treatments using a beneficial microorganisms either single or in a combination of more than two bioinoculants to protect the seeds from various seed- and soil-borne pathogens. Therefore, this article highlights that to understand the importance of biopriming, consortium formulation, and determination of dose, increases self-life and applicability of bio-priming agents in restoring soil health, improving plant nutrition, and maintaining crop/seed quality has a major role in achieving the sustainable development in agriculture in upcoming generation.

Introduction

Seed is the fundamental need of agriculture. All agricultural operations starting with sowing of seeds and being most important input to agriculture, food production mainly depends on the availability and quality of seeds. Seed can play a crucial role in achieving high yield potential as quality seeds alone could increase productivity by 15-20%. Therefore, protecting the seeds from various biotic and abiotic stresses is prerequisite for healthy plants and vigorous yield. The quality of seeds can be enhanced by different methods such as physical, mechanical, and chemical treatments through different techniques of seed treatments including seed invigoration/ priming, seed coating and seed pelleting. Among them seed priming which include hydropriming, halopriming, thermopriming, osmopriming, solid matrix priming and seed bio-priming in which biopriming is one of the most simple and feasible methods to protect seeds from seed-borne and soil-borne pathogens. Presently, rapid explosion of human population worldwide, the production of food may soon become insufficient to feed all the global population. Therefore, to boost the agricultural productivity, agricultural practices are shifting towards more sustainable approach of using plant growth promoting bacteria, biofertilizers, fungal bioagents, transgenic plants etc. However, seed treatments through physical and chemical method have limited effectiveness rather than biological seed treatments. Seed bio-priming is one of the vital and versatile tools for protecting the seeds from various biotic and abiotic stresses and improving the vigour indices, viability, efficiency and rapid establishment of healthy seedlings in the field without causing any hazardous effects on plant, human and animal health.

What is Seed Bio Priming

Bio-priming is a process of biological seed treatment that refers to a combination of seed hydration and inoculation of the seeds with beneficial microorganisms.It is a viable and environmentally sound ecological approach technology that can make integrated nutrient management plans more efficient. Seed bio priming has emerged out to be the most feasible, cost effective, economic and eco-friendly seed treatment method with a combination of beneficial microorganisms (biological aspects) and seed hydration (physiological aspects)which results in improved seed quality and increased seed viability, enhanced physical and physiochemical properties of the seeds and protect the seed from various seed- and soil-borne diseases. Apart from that it provides increased seed germination, crop vigourness, crop nutritional quality, improved water use efficiency, protection from biotic and abiotic stress includingsalinity, drought, low fertility and heavy metals,andreduction in environmental contamination and ultimately improvesover all plant health which leads to enhancement of crop yield. Bio priming process has potential advantages over simple seed coating with bioagents as the former one maintains rapid and uniform seedling emergences even under adverse soil conditions.

Objective of seed bio priming

The prime objective of seed bio priming is to increase seed performance in many of the following ways

- To reduce the use of agrochemicals detrimental to nature and/or non-target organisms.
- To eliminate any threat posed by seed and soil-borne phytopathogens and triumph over phytochrome induced dormancy in plants.
- To enhance germination rate and vigourness of seedling
- To improve the physiological and biochemical attributes in bio-primed seeds
- To reduce the dependency of chemicalsfor seed treatments and promotes biological seed treratments which is safer for soil, plant and environmental health.
- To explore microbial diversity and restoration of ecosystem.
- To promote IDM effectively in sustainable agriculture and maintain global food security and helps to mitigate global warming and climate change impacts.

Advantages of seed bio-priming

There is plethora of advantage of seed biopriming over the chemical treated seeds and the enzymatic activity in soil is mostly of microbial origin. Soil enzymes are key factors for improving soil fertility or nutrient availability to plants.It improves overall health status of plants including growth promotion (vegetative and dry matter accumulation), yield, nutrition, and quality of crops. Seed bio-priming of rice with phosphate solubilisation bacteria (PSB) which increases the urease, phosphatise and dehydrogenase activity in rhizospheric soils. In addition to that seed inoculated with bacterial strains like *Bacillus subtilis* and *Pseudomonas fluorescens* which induce biochemical traits like cellulase, protease, catalase, amylase, dehydrogenase, urease, acid phosphatase, alkaline phosphatase, and phytase enzymes activities in rhizosphere soil. The increase in antioxidant enzymes such as ascorbate peroxidase (APX), catalase (CAT), phenylalanine ammonia-lyase (PAL), peroxidase (PO), polyphenol oxidase (PPO), chitinase (Chi) and defense genes such as pathogenesis-related (PR) proteins, PAL, Lipoxygenase (*LOX*), and *Chi* (chitinase) was observed when seed treated with bio agents (bio-primed seed). Several strains of PSB including *Pseudomonas aeruginosa*, *B. subtilis*, *Erwinia tasmaniensis*, and *Staphylococcus epidermidis* have shown a positive response to PGP substances, viz., IAA and gibberellic acid (GA), ethylene (stress harmone) and ACC deaminase activity during their biochemical characterization. Apart from that secretion of organic acids and siderophores are important mechanisms adopted by microbes that help in the chelation of metal ions and complex formation to make the nutrient available for plant uptake the strains of phosphate solubilizers (*P. aeruginosa*, *B. subtilis) and* accumulation of phenolic compounds, *viz.*, gallic acid, shikimic acid, syringic acid, tannic acid, etc. were observed in plant when treated with microbial consortium.

Seed bio priming agents (bio-agents)

Microbial interactions are not limited to seed microbiome and plant microbiome.Broadly, the relationship of bioagents with their host may be rhizospheric or endophytic. Endophytic microbes colonize the inner tissue of plant parts whereas rhizospheric microbes colonize the rhizosphere and rhizoplane of the host. In the rhizosphere, A series of interactions take place in the form of exudation,

Table 1 Example of some selected biopriming agents in sustainable crop production

Bio inoculants	Dose	Host crop	Mechanisms	Positive impacts	References
Pseudomonas fluorescence (1×10^8 CFU mL^{-1}) Trichoderma harzianum (1×10^7CFU mL^{-1})	--	Cumin	Increase in antioxidant enzyme activities (APX, CAT) in seeds, soluble protein in leaf, root length	Improved seed germination, seedling establishment, shoot length under drought stress	Piri et al. (2019)
Bacillus amyloliquefaciens (1×10^7 CFU mL^{-1})	--	Rice	Induction of systemic resistance, increase in antioxidant enzyme activities (PO, PPO)	Reduced disease severity of blast caused by Magnaporthe oryzae, increased grain yield under field conditions	Amruta et al. (2019)
Trichoderma asperellum (1×10^7 CFU mL^{-1})	--	Tomato	Increased accumulation of total phenol and antioxidant enzyme activities such as PAL, PO, PPO, and Chi in plants; induction of defense genes such as *PAL*, *Chi*, *LOX*, and *PR*	Improved seed germination, reduction of disease incidence (Fusarium Wilt caused by Fusarium oxysporum f. sp. lycopersici)	Singh et al. (2020)
Enterobacter spp. (1×10^8 CFU mL^{-1})	--	Okra	Root colonization, P and K solublization, secretion of organic acids such as gluconic acid, malic acid, and citric acid	Increased leaf surface area, SPAD chlorophyll index, plant P and K uptakes, soil fertility	Roslan et al. (2020)
Trichoderma viride (2×10^5 CFU mL^{-1})	10 g kg-1 seeds	Soybean	Root elongation, soil P solublization by acid phosphatase activity	Increased P acquisition in plants, reduced application of P-fertilizer dose	Paul and Rakshit (2021)
Pseudomonas fluorescens, Pseudomonas gessardii, Bacillus subtilis, Bacillus mojavensis (1×10^8 CFU mL^{-1})	5ml g-1 seeds	Pepper	Synthesis of phytohormones	Increased seed germination and seedling emergence	Yildirim et al. (2021)
Bacillus cereus, B. amyloliquefaciens, Bacillus megaterium	--	Spinach	Reduction in metal uptake, biosorption, biotransformation, complexation, increased SOD	Growth promotion (root and shoot length, fresh and dry root and shoot weight) under the stress of heavy metals like As, Cr, Ni, and Pb	Renu et al. (2021)

organic matter decomposition, nutrient mobilization, remediation, competition, etc.Microorganisms capable of colonizing the rhizosphere or plant roots, facilitate nutrient availability for plant uptake. The rhizospheric effect is in the action mainly due to the easily available carbonaceous substrates (exudates and mucilage) release by plant roots in soil. The bioagents used in seed priming are mostly various species of bacteria and fungi. Beneficial bacteria in rhizosphere may form symbiotic relationship through specialized structures or may be free living that often known as Plant Growth Promoting Rhizobacteria (PGPR). PGPR include a wide range of bacteria belongs to the genera *Bacillus, Pseudomonas, Serratia, Azospirillum, Azotobacter, Agrobacterium, Rhizobium* etc. Such bacteria are screened on the basis of Nitrogen fixation, Phosphorus solublization, phytohormone production, antifungal activity and production of other organic compounds. Among fungal genera, *Trichoderma* is the most popular and beneficial agent in biopriming. This particular fungus genera have potentiality to mobilize nutrients from the soil, enhances root development, induces systemic resistance and also protects the plants against pathogens through various mechanisms such as parasitism, competition, antibiosisand lysis. Besides *Trichoderma*, some other fungal genera i.e.*Alternaria, Aspergillus, Cladosporium, Fusarium, Gliocladium, Glomus, Verticillium, Penicillium* are also capable to act as seed bio priming agents.

Mechanism of Biopriming

Bio-priming is an important tool to strengthen the mechanisms of seed-microbe-soil-plant interactions. The mechanisms behind these associations are complex, nevertheless, deeper understandings of such modes of action can form vital strategies for improving the growth, yield, and nutrient use**.**

Types of seed bio priming

On the basis of number of microorganisms used, bio priming can be classified into two types viz: Single species priming and Consortium priming. In former, the process of application of single microorganism or strain/ bioagents and it is very simple method of microbial application in agroecosystems.

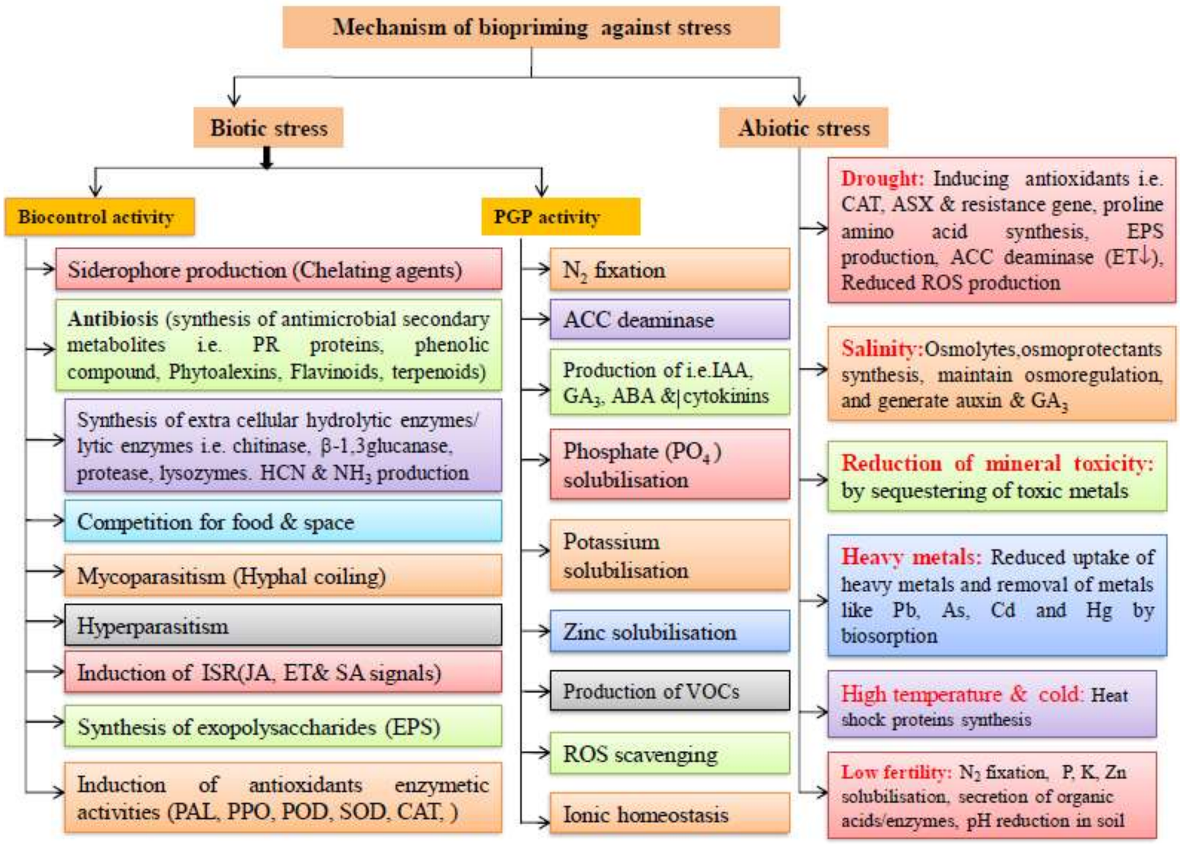


Fig 1 : Pictorial representation of different mechanisms of biopriming against biotic and abiotic stress

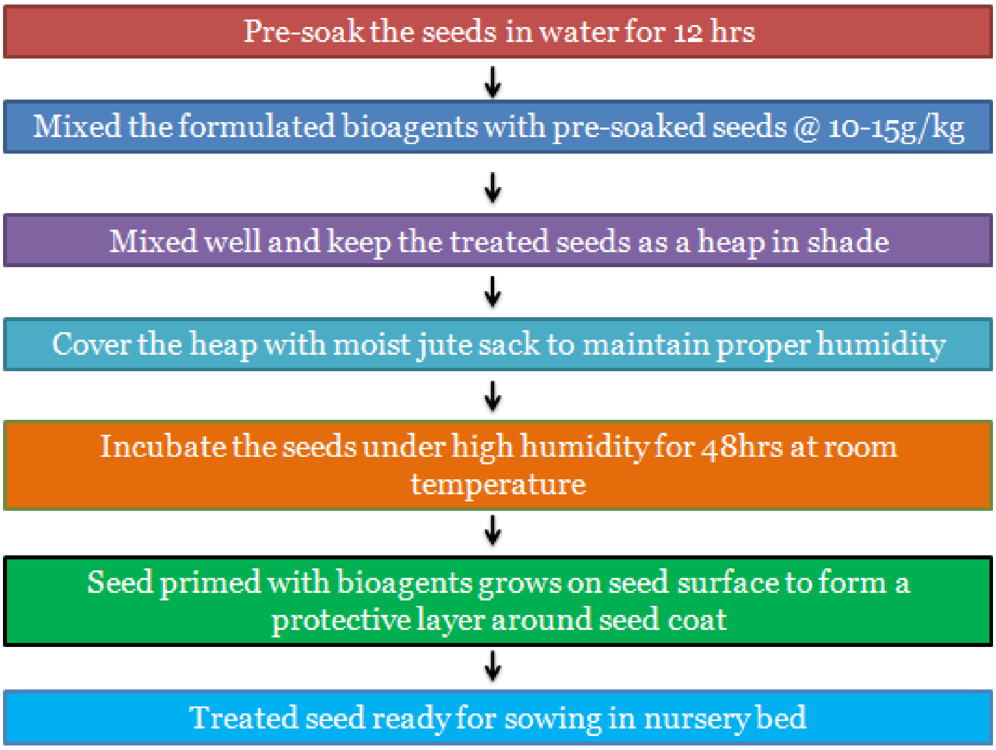


Fig. 2 General procedure of seed biopriming

Compared to single species priming, co-inoculation or consortium priming, which imparts use of multiple microorganisms/bioagents in the inoculation process for harnessing the maximum benefits in plant productivity as compared to the single inoculation with the aim of improving absorption of nitrogen, phosphorus and other minerals by seed crops. In consortium bio priming, compatible microbes may produce more synergistic effect on plant growth as well as on disease management.

Methodology of seed bio priming

Pre soak the seeds in water for 12 hours. Then mix the selected formulated product of the bioagent with the pre soaked seeds @ 10-15 g/kg. The treated seeds are kept in polythene bag, heaped and cover with a moist jute sackfor about 48 hours at approximately 25-32°C to maintain high humidity. During this period, the primed bioagent grows on the seed surface under moist conditions to form a protective layer around the seed coat. The bio primed seeds then can be sown the in-nursery bed and can be stored safely up to 2 months.

Conclusion and future prospects

Seed bio-priming is one of the versatile and reliable techniques of seed treatment with the aim of maintaining the food, nutritional, and health security and will help us in promoting sustainable agriculture. Therefore, government policies including commercialization and mass culturing of bio-inoculants have a crucial role in popularizing such techniques. Bio priming creates a complementary environment for seed inoculants by enhancing nutrient uptake from seed exudates. At present, bio priming of seeds as well as development of potential priming agents are very essential. Hence, there is a need of proper identification of potential strains of bioagents, development of formulation and their suitable mode of application. Seed bio priming can act as a model system for injection of beneficial microorganisms in soil. Though seed biopriming is a versatile technique with copious advantages in sustainable agriculture. However, the major constrains coupled with seed bio priming is to maintain the high numbers of beneficial microbes on seed surface during seed treatment and storage. Further, the importance of seed is neglected many times. Farmers need special training to conserve the bio-primed seeds and apply the microbes following the proper information on crops and duration of treatments. These interventions will make them self-reliant and harness multiple benefits from nature-based solutions. Therefore, further research needs to be devised to overcome the major constrain and also there is a needs for genetic manipulations of novel biocontrol agents and their mode of action on bio primed seeds. Moreover, this bio priming technique could be efficiently used to integrate both bioagents and pesticides for successful plant disease management.

REFERENCES

- Amruta, N., Prasanna Kumar, M.K., Kandikattu, H.K., Sarika, G., Puneeth, M.E., Ranjitha, H.P., Vishwanath, K., Manjunatha, C., Pramesh, D., Mahesh, H.B., Narayanaswamy, S., 2019. Bio-priming of rice seeds with novel bacterial strains, for management of seedborne *Magnaporthe oryzae* L. Plant Physiology Reports. 24 (4), 507–520.
- Bisen, K., Keswani, C., Mishra, S., Saxena, A., Rakshit, A., & Singh, H. B. (2015). Unrealized potential of seed biopriming for versatile agriculture. *Nutrient use efficiency: from basics to advances*, 193-206.
- Paul, S., Rakshit, A., 2021. Effect of seed bio-priming with *Trichoderma viride* strain BHU- 2953 for enhancing soil phosphorus solubilization and uptake in soybean (*Glycine max*). J. Soil Sci. Plant Nutr. 21, 1041–1052
- Piri, R., Moradi, A., Balouchi, H., Salehi, A., 2019. Improvement of cumin (*Cuminum cyminum*) seed performance under drought stress by seed coating and biopriming. Sci. Hortic. 257, 108667
- Rajendra Prasad, S., Kamble, U. R., Sripathy, K. V., Udaya Bhaskar, K., & Singh, D. P. (2016). Seed bio-priming for biotic and abiotic stress management. *Microbial Inoculants in Sustainable Agricultural Productivity: Vol. 1: Research Perspectives*, 211-228.
- Renu, Sarim, K.M., Sahu, U., Bhoyar, M.S., Singh, D.P., Singh, U.B., Sahu, A., Gupta, A., Mandal, A., Thakur, J.K., Manna, M.C., 2021. Augmentation of metal-tolerant bacteria elevates growth and reduces metal toxicity in spinach. Bioremediation Journal. 25 (2), 108–127
- Roslan, M.A.M., Zulkifli, N.N., Sobri, Z.M., Zuan, A.T.K., Cheak, S.C., Abdul Rahman, N. A., 2020. Seed biopriming with P-and K-solubilizing *Enterobacter hormaechei* sp. improves the early vegetative growth and the P and K uptake of okra (*Abelmoschus esculentus*) seedling. PloS ONE. 15 (7), e0232860 https://doi.org/10.1371/journal. pone.0232860.
- Sarkar, D., Singh, S., Parihar, M., & Rakshit, A. (2021). Seed bio-priming with microbial inoculants: A tailored approach towards improved crop performance, nutritional security, and agricultural sustainability for smallholder farmers. *Current Research in Environmental Sustainability*, *3*, 100093.
- Singh, P., Singh, J., Ray, S., Rajput, R.S., Vaishnav, A., Singh, R.K., Singh, H.B., 2020. Seed biopriming with antagonistic microbes and ascorbic acid induce resistance in tomato against Fusarium wilt. Microbiol. Res. 237, 126482.
- Yildirim, K.C., Canik Orel, D., Okyay, H., Gursan, M.M., Demir, I., 2021. Quality of immature and mature pepper (*Capsicum annuum* L.) seeds in relation to bio-priming with endophytic *Pseudomonas* and *Bacillus* spp. Horticulturae. 7 (4), 75. https://doi. org/10.3390/horticulturae7040075.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Gottemukkula Bhavani
Subject Matter Specialist-Agricultural Extension-KVK(YFA)- Mahabubnagar-I, Wanaparthy, Telangana, India

T.V. Kumar
Subject Matter Specialist-Agricultural Extension- KVK, Ramagirikhilla, Peddapalli Telangana, India.

ARTICLE ID: 27

Rebuilding Soil Organic Carbon for Sustainable Agriculture: Scientific Insights and Farmer-Centric Management Practices

Abstract

Soil health forms the backbone of sustainable agriculture, food security, and rural livelihoods. Over the past decades, a significant decline in soil organic carbon (SOC) has emerged as a major concern, particularly in intensively cultivated countries like India. SOC, once relatively abundant, has drastically reduced due to continuous cropping, excessive tillage, imbalanced fertilizer use, and neglect of organic inputs. This decline has adversely affected soil structure, nutrient cycling, water retention, and biological activity, ultimately reducing crop productivity and resilience. This article examines the scientific importance of soil organic carbon and its role in maintaining soil physical, chemical, and biological integrity. It further analyzes the key drivers responsible for SOC depletion and presents a comprehensive set of farmer-level management practices aimed at restoring soil fertility. Emphasis is given to practical, scalable, and eco-friendly approaches such as conservation tillage, residue management, organic inputs usage, green manuring, biochar application, and integrated nutrient management. The article also highlights the importance of institutional support, policy interventions, and community-level participation in soil restoration efforts. Strengthening soil health through sustainable practices is essential not only for enhancing agricultural productivity but also for mitigating climate change and ensuring long-term environmental sustainability.

Introduction

Soil is not just a medium for plant growth; it is a living, dynamic system that supports ecosystems, agricultural productivity, and rural economies. In regions where agriculture forms the primary livelihood, soil health directly influences food security, employment, and socio-economic stability. One of the most critical indicators of soil health is soil organic carbon (SOC). It represents the organic matter present in soil, derived from plant residues, animal waste, and microbial biomass. Historically, soils contained higher levels of organic carbon, but with the intensive agricultural practices over the decades have led to a drastic decline of this SOC. This reduction has serious implications for soil fertility, crop yields, and environmental sustainability.

The transformation of agriculture during the Green Revolution significantly increased food production, but it also introduced input-intensive practices. Over-reliance on chemical fertilizers, continuous monocropping, and led for the negligence of organic input usage which later on disrupted the natural balance of soil ecosystems. As a result, soil gradually losing its organic matter, leading to declining productivity and increased vulnerability to climate stress.

Restoring soil organic carbon is therefore essential for sustainable agriculture. It not only enhances soil fertility but also contributes to climate change mitigation by sequestering atmospheric carbon dioxide. This article explores the importance of SOC, the causes of its depletion, and farmer level practical strategies for its restoration.

Scientific Importance of Soil Organic Carbon: Soil organic carbon is often regarded as the central component of soil health due to its multifaceted role in maintaining soil functionality.

1. **Physical Functions:** SOC improves soil structure by binding soil particles into stable aggregates. This enhances porosity, reduces compaction, and increases water infiltration and retention. Soils rich in organic carbon are better able to withstand drought conditions, as they retain moisture for longer periods.
2. **Chemical Functions:** Organic carbon acts as a reservoir of essential nutrients such as nitrogen, phosphorus, and sulphur. It improves cation exchange capacity (CEC), enabling soils to retain and supply nutrients efficiently. Additionally, SOC buffers soil pH and reduces nutrient losses through leaching
3. **Biological Functions:** SOC serves as a primary energy source for soil microorganisms. A higher organic carbon content promotes microbial diversity and activity, which in turn enhances nutrient cycling, organic matter decomposition, and disease suppression
4. **Environmental Functions:** By storing carbon in the soil, SOC reduces greenhouse gas emissions and contributes to climate change mitigation. It also improves soil resilience against erosion and degradation.

Causes of Decline in Soil Organic Carbon: The depletion of SOC is primarily driven by changes in agricultural practices over time.

1. **Reduced Use of Organic Inputs:** Traditionally, farming systems relied heavily on farmyard manure and crop residues. With the shift towards chemical fertilizers, the application of organic materials has significantly declined, reducing carbon inputs to the soil.
2. **Imbalanced Fertilizer Use**: Excessive and unbalanced application of nitrogen, phosphorus, and potassium disrupts soil nutrient balance and accelerates organic matter decomposition and also increase micro nutrient deficiencies
3. **Intensive Tillage:** Frequent and deep ploughing accelerates the breakdown of soil organic matter by exposing it to air (oxygen), which enhances microbial oxidation. This process leads to the rapid release of carbon dioxide into the atmosphere, thereby reducing soil organic carbon (SOC) levels. Continuous intensive tillage also disrupts soil structure, reduces aggregate stability, and increases susceptibility to erosion, ultimately degrading soil health.
4. **Crop Residue Burning**: Burning of crop residues results in the immediate loss of valuable organic matter and essential nutrients such as nitrogen, phosphorus, and sulphur. It also destroys beneficial soil microorganisms and reduces microbial activity. In addition, residue burning contributes significantly to air pollution and greenhouse gas emissions, while preventing the natural recycling of carbon back into the soil system.
5. **Continuous Monocropping:** Continuous cultivation of the same crop, particularly intensive systems such as paddy–paddy cropping, leads to nutrient imbalance and depletion of specific soil nutrients. Such practices reduce biodiversity in the soil ecosystem and negatively affect soil structure and microbial diversity. Over time, monocropping can alter soil pH, increase the risk of soil salinity or acidity (depending on management), and make the soil less suitable for diversified cropping systems in the future.
6. **Lack of Soil Testing Practice**: Application of fertilizers without proper soil testing leads to inefficient and imbalanced nutrient management. Farmers often apply fertilizers based on assumptions rather than actual soil nutrient status, resulting in excessive accumulation of certain nutrients while others remain deficient. This imbalance not only reduces nutrient use efficiency but also contributes to soil degradation, micronutrient deficiencies, and declining crop productivity.

Farmer-Level Management Practices for Enhancing SOC: Restoration of SOC requires a combination of sustainable agricultural practices that are both *practical and economically viable for farmers*.

1. **Conservation Tillage:** Reducing soil disturbance through minimum or zero tillage helps conserve organic carbon by limiting oxidation. It also improves soil structure, moisture retention, and microbial activity. Example Zero tillage, Ridge tillage, Strip tillage, Mulch tillage and minimum tillage
2. **Crop Residue Management:** Incorporating crop residues into the soil rather than burning them enhances organic matter content. Residues can also be composted using microbial cultures to accelerate decomposition and improve nutrient availability. For example, with a rotavator which is a highly effective for chopping and mixing residues into the soil in a single pass, then that speed up for decomposition.
3. **Application of Organic inputs:** Application of organic inputs such as farmyard manure, compost, and vermicompost and certain concoctions like jeevamurtham and Panchagavya especially widely used in natural farming practices that significantly improves soil fertility. These inputs enhance humus formation, increase microbial activity, and improve soil structure.
4. **Bio fertilizers:** Unlike chemical fertilizers, biofertilizers improve soil health without causing degradation. They enhance root growth, increase nutrient uptake, and promote the accumulation of organic matter in the soil. Biofertilizers are living microorganisms that rebuilds soil organic carbon by stimulating microbial processes and supporting sustainable nutrient cycling. For example - Nitrogen-fixing bacteria (Rhizobium, Azotobacter, Azospirillum) Convert atmospheric nitrogen into plant-available forms, Phosphate-solubilizing bacteria (PSB) Make insoluble phosphorus available to plants, Potassium mobilizers**:** Release potassium from soil minerals and Mycorrhizae**,** Improve root surface area and nutrient absorption.
5. **Green Manuring and Crop Rotation:** Growing green manure crops such as Sunnhemp (Crotalaria juncea), Dhaincha (Sesbania aculeata / Sesbania bispinosa), Sesbania rostrata, Green gram (Moong) (Vigna radiata), Black gram (Urd) (Vigna mungo), Cowpea (Vigna unguiculata), Horse gram (Macrotyloma uniflorum) and Cluster bean (Guar) (Cyamopsis tetragonoloba) and green leafy manure such as Gliricidia (Gliricidia sepium), Subabul / Leucaena (Leucaena leucocephala), Neem (Azadirachta indica), Pongamia / Karanja (Pongamia pinnata), Calotropis (Jilledu) (Calotropis gigantea) and Sesbania grandiflora (Agathi) and incorporating them into the soil enriches organic carbon and nitrogen content. Crop rotation, especially with legumes/ oilseed crops, improves soil fertility and breaks pest cycles.
6. **Cover Cropping and Mulching:** Cover crops such as legume crops like Cowpea Green gram, Black gram, Sunhemp and Horse gram and non- legume crops like Mustard, and Millets that protect soil from erosion, suppress weeds, fix atmospheric nitrogen and add organic matter. Mulching especially Paddy straw, Wheat straw, Maize stalks, Cotton stalks (chopped), Groundnut shells or Dry Leaf Mulch reduces soil temperature, conserves moisture, and supports microbial activity.
7. **Integrated Nutrient Management (INM):** Balanced use of organic and inorganic fertilizers ensures efficient nutrient supply while maintaining soil health. Combining biofertilizers with organic inputs enhances nutrient availability and reduces dependency on chemical fertilizers.
8. **Soil Testing and Need-Based Fertilizer Application:** Soil testing that provides critical

information on soil properties such as pH, electrical conductivity, organic carbon, and the availability of macro and micronutrients. Fertilizer application based on soil test recommendations ensures that nutrients are supplied in the right quantity, proportion, and timing. This approach is often referred to as Site-Specific Nutrient Management (SSNM) that support the buildup and maintenance of soil organic carbon for sustainable agricultural productivity.

9. **Livestock integration:** Incorporating livestock into farming systems provides a continuous source of organic manure. Grazing and penning of animals contribute to nutrient recycling and soil fertility improvement.

Conclusion:

The decline in soil organic carbon is a critical challenge that threatens agricultural sustainability, food security, and environmental health. However, it is also reversible through informed management practices and collective efforts. Enhancing soil organic carbon is not just about improving yields; it is about restoring the life of the soil. By adopting conservation agriculture, recycling organic resources, and integrating scientific knowledge with traditional practices, farmers can rebuild soil fertility and resilience.

Sustainable soil management must be viewed as a long-term investment rather than a short-term intervention. Sustainable soil management requires collective action. Strengthening village-level institutions and promoting awareness can facilitate adoption of sustainable practices. Besides with right policy supports for natural farming, biofertilizers, and soil restoration initiatives is essential for large-scale impact.

With appropriate policy support, institutional involvement, and farmer participation, it is possible to achieve productive, climate-resilient, and environmentally sustainable agricultural systems.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Fathima Mariyam Sa adiya

Student of Soil and Water Conservation Engineering in CIAE Bhopal

Dr. Sandip Gangil

Principal scientist, Agricultural Energy and Power Division ICAR, CIAE Bhopal

ARTICLE ID: 28

SENSOR-BASED AUTOMATION IN DRIP IRRIGATION

Abstract

Sensor-based automation for drip irrigation integrates in-field sensors, embedded controllers, communications, and control algorithms to deliver water precisely to crop root zones. By replacing calendar-based schedules with data-driven actuation, sensorised drip irrigation systems reduce water use, minimise plant water stress, and improve yield stability under variable climatic conditions. This article reviews sensor types, system architectures, control strategies (threshold, PID, fuzzy logic, ET-based) and deployment considerations (sensor placement, calibration, power, communications) for researchers and practitioners. Representative recent studies demonstrating water savings and reliability improvements are cited.

1. Introduction

Global agriculture consumes approximately 70% of freshwater withdrawals; improving irrigation efficiency is essential for sustainability and food security. Drip irrigation already offers high application efficiency by delivering water near the root zone, but standard operation often relies on fixed schedules that do not account for spatial and temporal variations in soil moisture, crop demand, or system faults (clogging, pressure drops). Estimation of water content based on sensor measurements provide real time, in situ measurements at a relatively affordable cost. Soil moisture sensors potentially provide the means to irrigate in accordance with the unique characteristics of a given crop in a given field. Embedding sensors (soil moisture, soil temperature, pressure/flow) and actuators with automated control yields sensor-based drip irrigation systems which dynamically modulate water application to actual crop and soil needs, improving water-use efficiency and resilience to variability. Recent field and simulation studies report notable reductions in water use and improved crop water status when sensor feedback is applied.

2. Sensors and measurements - principles and selection

2.1 Soil moisture measurement methods

Common soil moisture sensing technologies include:

- Time-Domain Reflectometry (TDR): Determine volumetric water content from dielectric properties of soil with several textures; widely used in automated systems for durability, low maintenance, and fast response.
- Neutron moisture meter**:** Determines volumetric soil water content by measuring the density of slowed (thermal) neutrons produced from interactions between fast neutrons and hydrogen atoms in soil water. It is highly accurate for profile measurements at medium to deep depths and provides an average moisture value over a relatively large soil volume. The method requires soil-specific calibration and involves strict radiation safety and regulatory controls.
- Resistive/conductivity sensors: inexpensive but sensitive to salinity and corrosion; require calibration for soil type.

- Resistive/conductivity sensors: inexpensive but sensitive to salinity and corrosion; require calibration for soil type.
- Tensiometer: Measures soil moisture as soil water tension (matric potential) using a water-filled tube with a porous ceramic cup and vacuum gauge. It is suitable for wet to moderately moist soils and widely used for irrigation scheduling; selection depends on soil texture, depth of measurement, and maintenance requirements.

Selection criteria: choice depends on desired metric (matric potential vs volumetric water content), soil texture, salinity, budget, and maintenance capacity. For precision drip systems, capacitance/FDR sensors are commonly preferred for real-time control with reasonable cost and robustness.

2.2 Auxiliary sensors

- Soil temperature: affects water availability and sensor calibration.
- Air temperature and relative humidity: for evapotranspiration (ET) estimation.
- Solar radiation or reference evapotranspiration stations: for crop water demand modelling.
- Flow and pressure sensors: for early detection of emitter clogging, pump issues, or line breaks.

3. System architecture and communications

3.1 Typical architecture

A practical sensor-based drip system comprises

(i) in-field sensors at representative locations/depths

(ii) local data acquisition nodes (microcontroller or edge-controller)

(iii) communication network (wired, ZigBee, LoRaWAN, NB-IoT),

(iv) cloud/backend for logging and analytics (optional), and

(v) actuators - solenoid valves or proportional controllers - that modulate flow.

Redundancy (multiple sensors per management zone) and valve zoning are recommended to accommodate spatial variability.

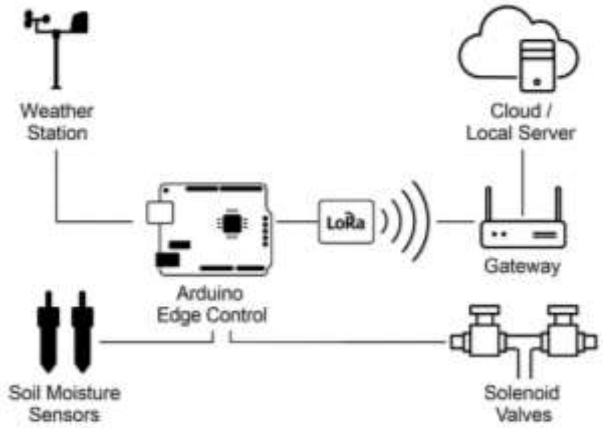


Fig 1. System architecture

3.2 Communications and energy

- Short-range mesh (ZigBee, IEEE 802.15.4): suitable for dense orchards/greenhouses with moderate range and mesh reliability.
- Long-range LPWANs (LoRaWAN, NB-IoT): low power, long range - suitable for dispersed fields but may have lower uplink capacity.
- Power: solar panels with battery buffering are commonly used for remote nodes. Proper energy budgeting is crucial when sensors sample frequently or when actuators are locally driven.

4. Control strategies

4.1 Threshold control

The simplest approach: irrigate when soil moisture or matric potential crosses a preset threshold and stop when a higher threshold is reached. This approach is valued for its simplicity and low computational requirements, but it can result in frequent on - off cycling and does not account for crop evapotranspiration, although it remains widely adopted in low - cost systems.

4.2 Model-predictive and ET-based scheduling

Use weather (or measured microclimate) to estimate crop evapotranspiration (ETc) and replenish root-zone water to target depletion levels. This anticipatory control reduces unnecessary actuation and aligns irrigation with crop demand, but requires reliable weather/ET inputs and accurate crop coefficients. Comparative studies show ET - based approaches can outperform simple threshold control in water savings and yield under variable climates.

4.3 Proportional-Integral-Derivative and adaptive

control

PID controllers adjust valve opening based on error between measured soil moisture and set point. Useful for proportional drip delivery (variable flow valves). PID requires tuning and may struggle with nonlinearity and delays in soil water dynamics.

4.4 Fuzzy logic and AI methods

Fuzzy logic controllers map imprecise inputs (soil moisture, temperature, crop stage) into irrigation decisions using linguistic rules; they handle uncertainty and nonlinearity well and have been successfully implemented in IoT drip systems. Recently, hybrid AI approaches (fuzzy + IoT, reinforcement learning) show promise for further optimisation, especially where detailed soil/crop models are unavailable. Multiple recent studies implement fuzzy/AI controllers with reported water savings and improved crop stress mitigation.

5. Design and deployment considerations

5.1 Sensor placement and sampling strategy

Place sensors in each management zone at root-zone depth representative of the crop (e.g.,15 - 30 cm for many row crops; deeper for trees). Use at least 2 - 3 sensors per zone to capture spatial variability when field heterogeneity is high. Sampling interval, balance responsiveness vs energy - common ranges are 15 min to 4 hours depending on dynamics and actuator latency.

5.2 Calibration and soil-specific models

Dielectric sensors must be calibrated to soil texture and bulk density; tensiometers may require correction for temperature. Calibration against gravimetric samples or laboratory TDR improves absolute accuracy and control reliability.

5.3 Fault detection and maintenance

Flow/pressure monitoring helps detect emitter clogging or leaks. Automated alerts and periodic self-tests reduce downtime. Design for easy sensor access and spare parts for field replaceability.

5.4 Economic and social factors

Upfront costs (sensors, controllers, communications) must be justified by water/energy savings and yield gains. Scalable designs (start with core zones) and modular upgrades (add more sensors over time) improve adoption among smallholders. Training and local technical support are critical for long-term success.

6. Case studies and recent findings

6.1 Smart sensor for automatic drip irrigation system for paddy cultivation

Sensor-based automation in drip irrigation represents a significant advancement in precision agriculture by integrating real-time sensing, image analytics, and automated control to align water application with actual crop demand. The analysed case study presents a smart drip irrigation architecture that combines soil image processing via a smartphone application with in-field environmental sensors measuring soil moisture, temperature, humidity, rainfall, and light intensity. Soil wetness is quantified through grayscale image histogram analysis, while sensor data is transmitted using a GSM module to an ARM-based microcontroller. This controller autonomously governs irrigation operations, switching the system on or off based on predefined decision logic and prevailing field conditions, and continuously updates farmers through mobile alerts. The approach eliminates fixed irrigation schedules and replaces them with responsive, data-driven water management, enhancing operational reliability and decision transparency.

From a performance and impact perspective, the field implementation on a one-acre paddy crop demonstrates substantial efficiency gains over conventional practices. Comparative results show that the smart sensor–based drip irrigation system reduces total water consumption by approximately 41% relative to traditional flood irrigation and by about 13% compared to standard drip irrigation. These savings are achieved by dynamically matching irrigation volumes to crop growth stages and environmental variability, particularly during early and mid-growth phases where water demand is lower. Beyond water conservation, the system reduces labour dependency, minimizes over-irrigation risks, and supports sustainable groundwater management, positioning sensor-driven automation as a scalable and economically viable solution for modern, resource-efficient agriculture.

7. Discussion - challenges and future directions

7.1 Challenges

Sensor drift and need for soil-specific calibration remain barriers for long-term accuracy, communications reliability and power constraints in large or remote fields and economic constraints for smallholder adoption.

7.2 Research directions

- Sensor fusion: combining matric potential and volumetric measurements to improve robustness.
- Adaptive learning controllers: reinforcement learning that adapts to local soil/crop dynamics while ensuring safety constraints (no crop stress) promises gains but requires careful field validation.
- Standardized benchmarks: shared datasets and benchmark trials to compare controllers under common conditions are needed to move toward best-practice recommendations. Recent initiatives and commercial pilots are beginning to provide open data and case studies.

8. Conclusion

Sensor-based automation in drip irrigation materially advances precision water management by aligning delivery with crop and soil needs. The optimal system balances sensor selection, communications and power constraints, and a control strategy tuned to crop and environmental dynamics. Field evidence indicates consistent water savings and operational benefits, but wider adoption will depend on reducing costs, improving robustness (calibration, fault detection), and providing farmer-friendly interfaces and support.

References

- Ahuchaogu, I. I., Okwong, E. E., Udoumoh, U. I., Ehiomogue, P. O., & Wilson, U. (2024). Development of an automated drip irrigation system using soil moisture sensor. *Poljoprivredna tehnika*, *49*(4), 1-15.
- Barkunan, S. R., Bhanumathi, V., & Sethuram, J. (2019). Smart sensor for automatic drip irrigation system for paddy cultivation. *Computers & Electrical Engineering*, *73*, 180-193.
- Baseca, C. C., Dionísio, R., Ribeiro, F., & Metrôlho, J. (2025). Edge-Computing Smart Irrigation Controller Using LoRaWAN and LSTM for Predictive Controlled Deficit Irrigation. *Sensors*, *25*(22), 7079.
- Gu, Z., Qi, Z., Burghate, R., Yuan, S., Jiao, X., & Xu, J. (2020). Irrigation scheduling approaches and applications: A review. *Journal of Irrigation and Drainage Engineering*, *146*(6), 04020007.
- Lozoya, C., Mendoza, C., Aguilar, A., Román, A., & Castelló, R. (2016). Sensor-based model driven control strategy for precision irrigation. *Journal of Sensors*, *2016*(1), 9784071.
- Munoth, P., Goyal, R., & Tiwari, K. (2016). Sensor based irrigation system: A review. *NCACE. USA.*
- Puspaningrum, A., Ismantohadi, E., & Sumarudin, A. (2021, March). Irrigation forecasting by using fuzzy logic on sensor data. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1098, No. 4, p. 042004). IOP Publishing.
- SU, S. L., Singh, D. N., & Baghini, M. S. (2014). A critical review of soil moisture measurement. *Measurement*, *54*, 92-105.
- Thompson, R. B., Gallardo, M., Valdez, L. C., & Fernández, M. D. (2007). Using plant water status to define threshold values for irrigation management of vegetable crops using soil moisture sensors. *Agricultural water management*, *88*(1-3), 147-158.

Just Agriculture Multidisciplinary *e- newsletter*

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Addya Singh

Research Scholar, Dept. of Genetics and Plant Breeding, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh (250110), India

Pooran Chand

Professor, Dept. of Genetics and Plant Breeding, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh (250110), India

ARTICLE ID: 29

Speed Breeding: An Advance Approach of Revolution

Abstract

The technology wherein the entirety reaches into the next generation by using increasing its price then why not plants? The query initiate from right here lead to a discovery of the eminent technique of breeding, that's pace Breeding. The drought, flood and worldwide losses because of weed, insect and pest ask for instant resistant sorts and through convention breeding the discharge took Approx 14 years for the brandnew variety to return in the marketplace on the market. that is the major cons from which breeders are suffering, despite the fact that the molecular breeding supplemented the conventional one, but it may be taken as the sole technique of application. for this reason, considering all this a brandnew approach evolved with elevated boom and reduced breeding cycle called speed Breeding. it's far known as elevated breeding.

1. Introduction

The globalization replaces the agriculture land areas with the most commercial plant, which is causing weather exchange along with various abiotic and biotic stresses. The growing stresses demanding for set off release of new resistant types. The breeding methods of both self and Cross-pollinated crops gave insight closer to a way to expand specific sorts however the evolution via these techniques has a very low tempo. The contemporary global has will increase the tools with extra work within the least time from a quick technique to short conversation; everything is growing its fee. This depicted that in future fastness is some other call modernization and advances. The era in which the whole thing reaches into the subsequent generation via increasing its fee then why not vegetation? The question provoke from here cause a discovery of the eminent approach of breeding, that is velocity Breeding. The drought, flood and worldwide losses due to weed, insect and pest ask for instant resistant varieties and thru conference breeding the release took approx 14 years for the brand new variety to come within the marketplace for sale. this is the essential cons from which breeders are struggling, even though the molecular breeding supplemented the traditional one, however it can't be taken as the sole method of utility. accordingly, thinking about all this a brand new technique evolved with accelerated growth and decreased breeding cycle called speed Breeding. It is acknowledged as expanded breeding. The better choice depth and charge of generation turnover under velocity Breeding might also enable a more rate of genetic advantage than direct area phenotyping **(Watson and Lee *et al*, 2019).**

2. How velocity breeding is higher than different expanded b1reeding?

When the query arises of decreasing the breeding cycles many strategies come into consideration and a few such methods among them are mentioned right here with their important drawback.

2.1 Non-molecular breeding strategies

- Rapid generation advancement shortens the development of variety with the aid of two years via the manipulation of growing conditions like appropriate seed set in less time.
- In commute breeding, one can take breeding in off-season additionally by way of growing it in distinctive appropriate locations. consequently, two generations per year can be taken, which reduces the time of the cycle to simply 1/2.

2.2 Molecular breeding strategies

- Marker-assisted choice gave authentic function of the selected range via phenotyping at the side of genotyping, which will increase accuracy, value and decreases time by means of some years.
- Genome choice makes a speciality of a massive quantity of DNA, not just one or two genes as done in MAS. This made the correct selection to boom genetic gain.

3. How Speed Breeding is accomplished?

To recognize the exact running, first we've to start with its principle of operating. the speed breeding is the mixture of principles of above acceleration breeding factors (Figure 1). The breeding is executed beneath the controlled artificial surroundings with synthetic situations like speedy technology advanced and it could also be grown in offseason as we do in the trip breeding method. the main concept of such innovation comes from NASA which has the goal to develop food vegetation and wheat in space.

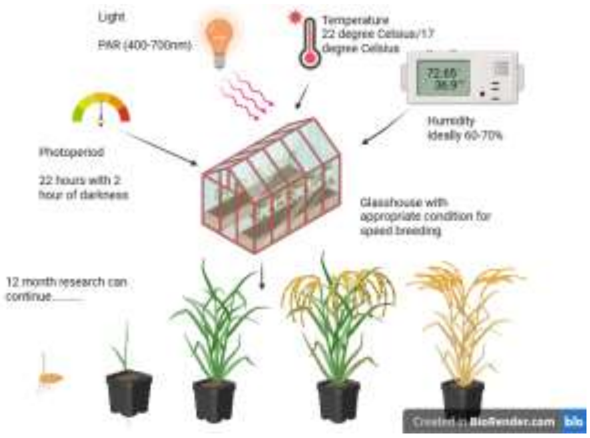


Figure 1. Representing the flowchart of speed breeding

4. Speed Breeding Set Up

- Light: PAR region (400-700),ambient lighting with LED
- Photoperiod: 22 hour with 2 hour of darkness
- Temperature: 22 °C/ 17 °C for 22 hours light and 2 hours dark.
- Humidity: Ideally 60-70% (Wanga *et al.*, 2021)

5. System of Speed Breeding

- To begin with, the seeds are organized for sowing by using offering the right remedy and environmental situations.
- The full-size developing degrees are taken into consideration and unique emphasis is given to phenotyping of simplest those stages. Just like the time of anthesis or flowering is determined and their related parameters are discovered.
- Majorly seed is harvested at an immature stage and then given specific bloodless treatment for maturation. Although the seed produces this manner relatively shrunk on hydration they regain their form and vigour and germinated. However, this process reduces the time from 15 days to three days
- The energy monitoring helps us to be particular whilst providing mild, temperature and different organic matter (Figure 2).

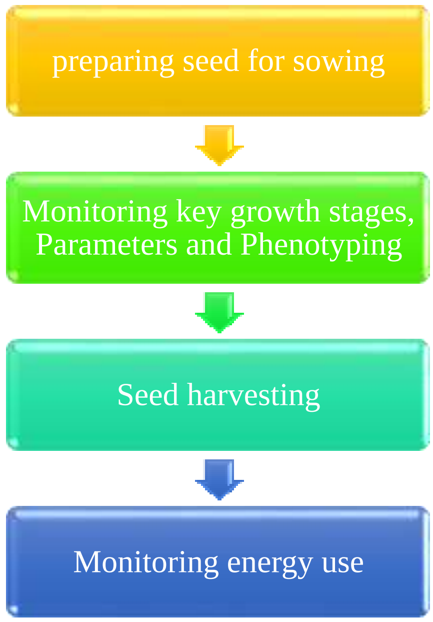


Figure 2. Procedure of speed breeding

6. Application

- Beneficial in growing more than one disorder resistance plants.
- Can collaborate with new generation like CRISPER CAS9 and deliver result in a shorter duration.
- Consistent with a few protocols, even eight-9 generations of barley were determined.
- There are numerous opportunities to combine it with transgenic and genomic selections to get right outcomes.
- Utility of a excessive-velocity breeding programme for disease resistance in apple. **(Flachowsky *et al*, 2011).**
- More than one portions developments in durum wheat.
- Mutant transformation for waxy tendencies in barley.

7. Achievement of speed breeding:

Area	**Achievement**	**Details / Examples**
Generation Advancement	Rapid generation cycling	Up to 4–6 generations/year in wheat, barley, chickpea, canola; as high as 8–10 in some crops under optimized conditions.
Breeding Program Acceleration	Shorter breeding cycles	Reduces traditional breeding cycles from 6–10 years to 2–4 years.
Genetic Gain Enhancement	Increased genetic gain per year	Faster turnover of populations accelerates response to selection in major crops.
Support for Genomic Selection	Quick population turnover	Enhances accuracy and speed of genomic selection pipelines.
Doubled Haploid (DH) Efficiency	Faster DH line production	Combined with DH tech, pure lines can be obtained within a year.
Mutagenesis & TILLING Programs	Rapid advancement of mutant populations	Speeds up development and fixation of desired mutants (e.g., wheat EMS mutants).
CRISPR/Cas Genome Editing	Quick recovery of edited lines	Allows fast generation of edited homozygous lines for trait validation.
Pre-breeding and Introgression	Accelerated incorporation of novel alleles	Introgression from wild relatives can be completed much faster.
Phenotyping Efficiency	Uniform and synchronized plant growth	Controlled environment improves precision phenotyping for disease, stress, and development traits.
Seed Production	Off-season seed multiplication	Provides rapid seed increase for trials when field seasons are limited.
Hybrid Development	Faster inbred-line development	Parental lines for hybrids can be developed 2–3× faster.
Disease Resistance Breeding	Rapid screening cycles	Enables quick pyramiding of R genes for rust, blight, mildew, etc.
Stress Tolerance Breeding	Faster screening under controlled stress	Allows early-generation testing for drought, salinity, and heat tolerance.
Learning & Research	Speeds student projects and research pipelines	Allows completion of M.Sc./Ph.D. gene validation and mapping studies in reduced time.
Economic Benefits	Reduced cost per generation	Significant savings in greenhouse space, time, and labor.

8. Future Challenges:

- There is a very excessive preliminary investment.
- As there is terrific range on this earth therefore the protocols are unique for unique crops. The response towards photoperiod is distinct for the specific vegetation therefore the protocols of glasshouse fluctuate among them.
- There may be an early harvest of immature spikes which interferes with the phenotyping of seed parameters.

Conclusion:

The technology in agriculture has explored every nook of studies and flora are completely exploited for improvement of the trait. The system makes use of the presently available facts of plant biology and its ecology to form a crop-precise protocol, control the photoperiod to shorten their lifestyles cycle, improve the boom via controlled surroundings condition inclusive of temperature, humidity, mild, and many others and level extraordinary assessment to in the long run advantage extra than 5-era in keeping with 12 months without reduction of yield is speed breeding. The scenario is no longer best centered on glasshouse manipulate measures but additionally taken plant requirements as the priority for setting up the protocols. the item discusses the important thing components with fundamental cynosure on wheat crops. the limitations which the technique involves are high preliminary cost and the protocols vary in difficulty with crop.

References:

1. Watson A, Hickey LT, Christopher J, Rutkoski J, Poland J, and Hayes BJ. (2019). Multivariate Genomic Selection and Potential of Rapid Indirect Selection with Speed Breeding in Spring Wheat. *Crop science*, 59.
2. William L. (2019). Bauerle Disentangling photoperiod from hop vernalization and dormancy for global production and speed breeding. *Scientific report* 9: 16003
3. O'Connora DJ, Wrightb GC, Dietersc MJ, Georged DL, Huntere MN, Tatnellf JR, and Fleischfresserg DB. (2013). Development and Application of Speed Breeding Technologies in a Commercial Peanut Breeding Program. *Peanut Science* 40: 107–114
4. Flachowsky H, Pierre-Marie Le Roux, Peil A, Patocchi A, Richter K and Hanke Magda-Viola. (2011). Application of a high-speed breeding technology to apple (Malus X Domestica) based on transgenic early flowering plants and marker-assisted selection. *New Phytologist*. 192: 364–377
5. Dwivedi, A., Kumar, S., Singh, R., Jha, N., Singh, V., & Debnath, A. (2021). Speed Breeding: A Contemporary Era of Revolution. *Biotica Research Today*, 3(12), 1172-1173.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

M. R. Dholariya

College of Horticulture, S. D. Agril. University, Jagudan, Gujarat

R. D. Savaliya

College of Horticulture, S. D. Agril. University, Jagudan, Gujarat

J.M. Zinzala

College of Horticulture, S. D. Agril. University, Jagudan, Gujarat

Dr. M. K. Sharma

College of Horticulture, S. D. Agril. University, Jagudan, Gujarat

Dr. D. A. Patel

College of Horticulture, S. D. Agril. University, Jagudan, Gujarat

ARTICLE ID: 30

THRIVING SUCCULENTS: TIPS, TRICKS AND CARE

Introduction

Beautifully eye-catching plants with stunning foliage are succulents. Because of the water retention capacity of their large, attractive leaves, they are drought-tolerant and comparatively self-sufficient plants. Succulents are quite visually appealing because they come in a variety of shapes, textures, colors, and heights, in addition to being low maintenance. Succulents thrive in a variety of settings, whether planted directly in the ground, nestled in pots, hidden in surprising locations, or incorporated into imaginative indoor and outdoor designs. Remove the uncertainty from their care with our comprehensive succulent guide, ensuring you cultivate vibrant, healthy plants that continue to flourish for years to come.

Caring of succulent

Succulents are practically self-sufficient when planted and cared for properly. Your attempts to cultivate succulents will succeed or fail depending on the right amount of sun, water, and soil conditions. Some considerations are mentioned below:

- Ideal Soil and pH
- Proper Sunlight
- Optimal Temperatures
- Amount and Frequency of Watering
- Fertilizing your Succulents
- Pests and Disease Prevention

Summer Succulents

In the spring, summer, and fall, succulents that are dormant in the winter will actively grow. Even though summer plants grow during the hottest days of the summer, their growth will slow down dramatically as temperatures fall below 40°F.

When a summer growing succulent starts its dormant period in the winter, it doesn't need a lot of water. If you notice the leaves becoming dry and wrinkled you can give them a drink. Otherwise, in most cases, you can leave the succulent alone until its growing season comes around again.

- Adenium
- Agave
- Alluaudia
- Brachystelma
- Bursera
- Calibanus
- Creopegia
- Cissus
- Cyphostemma
- Didieria
- Dorstenia
- Echeveria
- Encephalartos
- Euphorbia
- Fockea
- Huernia
- Ilbervillea
- Ipomoea
- Monadenium
- Pedilanthus
- Pterodiscu

Winter Succulents

"Winter growing" succulents are the most active during fall, winter, and spring—once nighttime temperatures drop below 60°F. These succulents go dormant in the heat of summer, they need to be protected from heat and still need to be watered at this time to keep their roots cool. Though these succulents are referred to as winter growers in the coldest days of winter, they will go through a mini dormancy and slow their growth.

- Aeonium
- Aloe
- Bulbine
- Ceraria
- Canophytum
- Crassula
- Dioscorea
- Dudleya
- Fouqueria
- Gasteria
- Graptopetalum
- Garptoveria
- Haemanthus
- Haworthia
- Kalanchoe
- Othonna
- Pachyveria
- Pelargonium
- Peperomia
- Portulacaria
- Sansevieria
- Sedevieria
- Sedum
- Senecio
- Stomatium
- Talinum

Succulent Soil

The soil in which succulents are planted directly affects their ability to grow. Succulents like growing in situations akin to drought and have shallow root systems. This means that, provided certain environmental conditions are met from the outset, they are an appealing, low-maintenance plant option.

- Succulents have shallow root systems and prefer soil that well-draining.
- A loose, rocky soil that is nutrient-rich is optimal.
- If planting in containers, use a potting mix specifically formulated for succulents and cacti and plant in a pot with holes in the bottom for drainage.
- Alkaline soil has the potential to cause the demise of succulent plants.
- You can amend soil with compost, perlite, pumice, decomposed granite, and sand.

Indoor succulents – Compressive guide

Starting with the optimal soil composition is crucial for the health of indoor succulents. Using a well-draining soil mix tailored for succulents or cacti sets the foundation for successful indoor care. This ensures proper moisture levels and supports robust root development.

In addition to soil, maintaining the right temperature is essential. Most indoor succulents flourish in temperatures ranging from 60°F to 65°F (15°C to 18°C) during the night. Keeping your indoor environment within this range will help your succulents thrive and stay vibrant.

By focusing on both the ideal soil mix and temperature, you'll create an optimal environment for your indoor succulents to grow and flourish.

When caring for succulents indoors, it is crucial to ensure that they receive at least 6 hours of sunshine per day. Too little sunlight will cause succulents to reach awkwardly for sunlight, resulting in spindly, blanched, and unbalanced plants. In place of sunlight, using grow lights for 12 to 14 hours per day will strongly help your plant's development and survival.

Watering regularly keeps the roots plump and leaves full of water for your succulents. However, watering too much can kill the plant. Keep your plants on the drier side; water a small amount, let it drain through, wait a week or so, check to see if there's any moisture left, then repeat the process.

Outdoor succulents care

Succulents are drought-tolerant plants because of the water storage capacity of their thick, distinctively formed leaves. Any landscape is made more visually attractive by the variety of intriguing shapes and textures that succulents may take on.

A common question is can succulents live outside? Yes, is the succinct response! They can withstand some neglect and grow well in bright, warm, dry areas. Thus, cultivating succulents outside is a fantastic choice.

Outdoor Succulent Tips:

- As long as the soil stays well-drained and there is some protection from harsh weather and sharp drops in temperature, hardy succulent species can be overwintered in pots or in the ground.
- It is advisable to bring more delicate succulent kinds indoors during the winter and set them in front of a sunny window. Additionally, you can put them under grow lights indoors to help them endure the winter's cold days.
- Reduce watering during fall and winter months so that succulents can survive cold temperatures.
- During the growing season, water more deeply, but less frequently.

Watering Succulents

One of the biggest mistakes people make when it comes to taking care of succulents is to give them too much water. Root rot is brought on by frequent root saturation and drying, and it eventually kills the plant.

Succulents thrive on a watering routine that emphasizes depth over frequency. For indoor succulents, water once a week, ensuring the soil is thoroughly moistened but not soggy. Always empty any water that collects in saucers beneath the pots to prevent root rot. Allow the soil to dry out completely between waterings. Outdoor succulents sh ould be monitored more closely; check the soil with your fingers and water only when it's dry. In the fall and winter, reduce watering to help your succulents withstand colder temperatures, as overly wet soil can increase the risk of frost damage.

Fertilizing Succulents

Many succulents can survive without fertilizer, applying a premium organic fertilizer can accelerate their growth and provide more vivid foliage and a profusion of blooms. Frequent feeding increases the longevity and general health of plants.

Choose a fertilizer made for succulents and cacti, ideally low in nitrogen and containing beneficial soil microbes to support optimal growth. A slow-release formula is ideal, as it provides steady nourishment without overwhelming the plant. To further safeguard against potential damage, consider diluting the fertilizer to prevent burning and ensure a gentle feeding process for your succulents.

- Like most containerized plants, some succulents can benefit from a nutrient-rich feeding routine.
- For optimal growth, apply the fertilizer in spring as new growth emerges and once again in fall.
- When growing succulents indoors, fertilizer can result in rapid growth, which can cause plants that aren't getting sufficient light to stretch in search of it. Consider temporarily moving your succulent plants outdoors to a partial sun spot just after fertilizing to help them retain their robust, compact nature as they soak in the beneficial nutrients.

Propagating succulents

Cuttings – Through a cutting of single leaves can grow into entire newly plant. Manually removed leaves from the plant without any damages and use one that fell off on its own use for the propagating.

Making divisions is a fairly simple way to propagate succulents. Certain succulents have a "mother plant" that is surrounded by offsets or babies, that grow from its base. Gently detach the roots and remove the offset from the mother with care. After that, replant in cactus soil and give it a little water.

Propagating succulents through water

Propagating succulents in water to create new plants from cuttings is a free and very simple method of expanding your succulent plant collection.

Spreading succulent joy, it also makes it simple to show off your new plants to friends and family.

Succulents can be multiplied by first using pruning shears to cut a healthy stem or offshoot from the parent plant and removing any lower leaves, leaving one to two inches of bare stem. To keep it from rotting, let the cut end calluses for a few days. Then, put it in a glass jar and soak the calloused end with distilled or rainwater. To maintain the water clear, replace the water in the jar every few days and place it in indirect sunlight. After the cutting has taken root, which should happen in three to six weeks, transplant it to an area that receives more direct sunshine.

Variegated succulents

Any green leaf you observe has chlorophyll; if you notice margins or markings that are varying hues of green, white, or yellow, it indicates that the chlorophyll concentration there is lower than it is in the green sections of the leaf. Variegation is the result of an unequal distribution of pigments, including chlorophyll.

In addition to chlorophyll, you're witnessing other pigments like carotenoid or anthocyanin when leaves exhibit various hues in addition to green, such as pink, purple, or orange. Stronger than ever, these other pigment colors have taken over.

Succulents sign and its causes

Brown spotting- Too much water, sunburn, fungus or pets

Yellowing- Overwatering or too much sun

Leggy and leaning- Not enough light

Shrivelling- not enough water

Conclusion

Hardy, low-maintenance, and aesthetically pleasing, succulents can grow inside or out with the correct soil, sunlight, hydration, and seasonal attention. They maintain their health and longevity while also adding aesthetic value when their growing requirements are properly addressed and propagated using easy methods. Succulents may bloom wonderfully and add sustainable greenery to any room if typical care mistakes are avoided and their specific needs are understood.

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Chavan G. M
Ph.D. Scholar, Department of Agricultural Processing Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, MPKV, Rahuri- 413722, Ahilyanagar, Maharashtra, India.

V. P. Kad
Associate Professor, Department of Agricultural Processing Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, MPKV, Rahuri- 413722, Ahilyanagar, Maharashtra, India.

K. J. Kamble
Professor and Head, Department of Agricultural Processing Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, MPKV, Rahuri- 413722, Ahilyanagar, Maharashtra, India.

V. A. Salve
Associate Professor, Department of Agricultural Processing Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, MPKV, Rahuri- 413722, Ahilyanagar, Maharashtra, India.

ARTICLE ID: 31

Integration of Virtual and Augmented Reality Technologies in Sensory Science

Introduction:

Virtual and augmented reality (VR and AR) technologies are revolutionizing sensory science by creating immersive environments that mimic real-world experiences, allowing researchers to study how our senses sight, taste, smell, touch and sound interact in controlled yet realistic settings. These tools go beyond traditional lab booths, enabling precise manipulation of contextual cues to explore perception, consumer preferences, and emotional responses, particularly in food and product evaluation. VR sensory booths simulate everyday scenarios like dining in a restaurant or shopping in a market, enhancing the ecological validity of tests that often feel sterile in standard setups. For instance, participants in VR environments report heightened engagement and more authentic sensory judgments, as visual and auditory cues influence taste perception such as making a white wine seem sweeter when paired with a beach scene. Studies show VR outperforms traditional methods by standardizing variables while boosting immersion, with positive feedback from users in food science experiments. Augmented reality overlays digital elements onto physical objects, letting researchers alter product appearance or context without changing the item itself like virtually colouring foods to test colour-taste associations. In sensory analysis, AR has revealed differences in liking scores for yogurts under AR conditions versus plain booths, highlighting its role in nuanced evaluations. Augmented virtuality, blending AR and VR, further refines controlled experiences for studying consumer behaviour with real products in virtual settings. These technologies extend to multisensory integration, where adding haptics or scents amplifies VR's effects on perception, though olfactory cues remain underexplored. In food science, VR/AR aids product development, training, and even precision agriculture sensory training, promising cost-effective, repeatable insights. As adoption grows, they bridge lab precision with real-life relevance, transforming how we understand human senses.

Source: Google

What is AR and VR?

Augmented Reality (AR)

- Integrates digital information with the user's environment in real-time.
- Typically accessed through smartphones, tablets, or AR glasses.
- Enhances the user's perception of the real world by overlaying digital elements such as graphics, text, or 3D models onto the physical environment.
- AR technology often relies on sensors like cameras and GPS to interact with the user's surroundings.
- Can be used for gaming, education, navigation, marketing and more.

Virtual Reality (VR):

- Immersive experience that transports users to a simulated environment.
- Accessed through VR headsets or goggles that cover the user's eyes and ears.
- Provides a sense of presence by blocking out the physical world.
- Users can interact with the virtual world.
- Applications range from gaming and entertainment to training, therapy, and virtual tourism.

How AR and VR works?

Augmented Reality (AR)

- Captures real-world surroundings using sensors like cameras and GPS.
- Analyzes the environment and identifies surfaces, objects, and features.
- Overlays digital content onto the user's view of the real world in real-time.
- Aligns digital elements with the user's perspective and adjusts them as the user moves.
- Utilizes software algorithms to blend virtual and real-world elements seamlessly.
- Interactions with AR content can be through touchscreens, gestures, or voice commands.

Virtual Reality (VR):

- Renders computer-generated 3D environments or scenes.
- Displays these environments to the user through a VR headset or goggles.
- Tracks the user's head movements in real-time.
- Utilizes motion-tracking sensors (e.g., gyroscopes, accelerometers).
- Includes input devices such as handheld controllers or gloves.
- Creates a sense of presence by stimulating the user's senses (visual, auditory).
- Requires powerful computing hardware and software.

Potential applications for virtual and augmented reality in sensory science

Enhanced Sensory Evaluation:

- VR and AR can create immersive environments that mimic real-world settings for more realistic sensory evaluations.
- Can control environmental factors like lighting, sounds, and background to assess their impact on sensory perception.

Consumer Behavior Studies:

- VR and AR can simulate shopping environments or dining experiences to study consumer behavior and preferences in different contexts.
- Enables researchers to observe naturalistic behaviors without the constraints of a physical location.

Training and Education:

- Sensory analysts and consumers can be trained using VR and AR environments to enhance their sensory evaluation skills.
- Provides a consistent training environment that can simulate various conditions and product scenarios.

Remote Sensory Testing:

- VR and AR can facilitate remote sensory testing, enabling participants to engage in sensory evaluations from their homes.
- Helps in expanding the reach of sensory studies to a broader and more diverse participant pool.

Contextual Influence Studies:

- Researchers can study how different environmental contexts influence sensory perception and preference.
- VR and AR can simulate a variety of settings, such as a quiet café or a busy street, to observe their effects on sensory experiences.

Multi-Sensory Integration:

- VR and AR can integrate multiple sensory inputs (visual, auditory, olfactory, etc.) to create a holistic sensory experience.
- Helps in understanding how different senses interact and contribute to overall perception and preference.

Conclusion:

Virtual and augmented reality technologies are emerging as powerful tools in sensory science by enabling researchers to create immersive and controlled environments that closely resemble real-life situations. These technologies enhance the accuracy and ecological validity of sensory evaluations by allowing the manipulation of contextual factors such as environment, visual cues and sound, which influence consumer perception and preferences. VR and AR also provide new opportunities for studying consumer behaviour, conducting remote sensory testing, and improving training for sensory analysts through standardized and repeatable environments. Overall, the integration of VR and AR has the potential to transform traditional sensory evaluation methods, making them more realistic, efficient, and versatile for future food and consumer research.

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

ARTICLE ID: 32

ROLE OF WIND ENERGY IN SUSTAINABLE DEVELOPMENT OF WESTERN RAJASTHAN AGRICULTURE

AUTHORS' DETAILS:

Dr. Ashish Pawar
Assistant Professor (Renewable Energy Engineering), College of Technology & Agricultural Engineering, Agriculture University Jodhpur RAJ 342304

Dr. Tarun Gehlot
Assistant Professor (Civil Engineering), College of Technology & Agricultural Engineering, Agriculture University Jodhpur RAJ 342304

Dr. Narender
Assistant Professor (Farm Machinery & Power Engineering), College of Technology & Agricultural Engineering, Agriculture University Jodhpur RAJ 342304

Introduction

Western Rajasthan, particularly districts such as Jodhpur, Barmer, Jaisalmer, Bikaner, and Jalore, represents one of the most challenging agro-climatic regions of India. The region is characterized by arid and semi-arid climate, low and erratic rainfall, high temperatures, frequent droughts, and limited irrigation resources. These factors significantly affect agricultural productivity and farmers' livelihoods. In such conditions, the adoption of renewable energy technologies plays an important role in improving agricultural sustainability. Among these renewable resources, wind energy has emerged as a promising alternative for supporting sustainable agricultural development in Western Rajasthan.

Wind energy refers to the conversion of kinetic energy of wind into mechanical or electrical energy using wind turbines. India has significant wind energy resources, and states such as Gujarat, Karnataka, Maharashtra, and Rajasthan possess high wind potential. According to the Ministry of New and Renewable Energy, India has an estimated wind power potential of about 695.5 GW at 120 m hub height, and Rajasthan alone contributes a significant share of this potential. The state has around 127.75 GW of wind power potential at 120 meters and about 284 GW at 150 meters, making it one of the leading states for wind energy development. Despite this huge potential, only a fraction of this energy resource has been harnessed so far. However, wind energy can play a crucial role in transforming the agricultural sector of Western Rajasthan by providing reliable, clean, and decentralized power solutions.

Wind Energy Potential in Western Rajasthan

The geographical and climatic conditions of Western Rajasthan are favourable for wind energy generation. The Thar Desert region experiences moderate to high wind speeds for a large part of the year.

Fig: Wind Farm Installed at Jaisalmer, Rajasthan

Open landscapes, low vegetation, and vast stretches of wasteland make the region suitable for installing wind turbines without major environmental disturbance.S tudies indicate that Rajasthan's total wind energy potential can reach up to 284 GW at higher hub heights, though currently only a small portion has been utilized. This large untapped potential offers significant opportunities for expanding renewable energy infrastructure in rural and agricultural areas.

Applications of Wind Energy in Agriculture

Wind energy can be applied in several agricultural activities in Western Rajasthan. These applications can help farmers reduce dependency on fossil fuels and grid electricity while improving farm productivity.

1. Wind Powered Water Pumping for Irrigation

Water scarcity is one of the biggest challenges for agriculture in Western Rajasthan. Wind-powered water pumping systems can provide an effective solution for lifting groundwater from wells or boreholes for irrigation. Traditional windmills have been used for water pumping for centuries, and modern wind turbines can now operate efficient pumping systems. These systems are especially beneficial for small and marginal farmers because they reduce operating costs associated with diesel pumps. Wind-powered pumps can supply water for drip irrigation systems, livestock watering, and domestic purposes in remote villages.

2. Electricity Generation for Farm Operations

Small wind turbines can generate electricity for various farm operations such as grain cleaning, milling, lighting, and powering small agricultural machinery. In remote areas where grid connectivity is unreliable, decentralized wind energy systems can ensure uninterrupted power supply. Wind energy systems can also support agricultural processing activities such as oil extraction, flour milling, and dairy operations. This helps farmers increase value addition and income.

3. Wind Energy for Cold Storage and Post-Harvest Management

Post-harvest losses are a major issue in agricultural supply chains. Wind energy can be used to power cold storage units, milk chilling centers, and food processing units in rural areas. These facilities help farmers store perishable products such as fruits, vegetables, and dairy products for longer periods. By reducing post-harvest losses, wind energy indirectly contributes to improving farmers' income and food security in the region.

4. Hybrid Wind–Solar Systems for Agriculture

Western Rajasthan receives abundant sunshine throughout the year, making solar energy another important renewable resource. Combining wind and solar energy in hybrid systems can ensure continuous electricity generation because wind often blows during evening and night hours when solar power is not available. Hybrid renewable energy systems can be used to operate irrigation pumps, farm equipment, rural micro-grids, and agricultural processing units. Such integrated systems improve energy reliability and reduce dependence on conventional electricity sources.

Environmental Benefits of Wind Energy in Agriculture

Wind energy is a clean and environmentally friendly energy source. Unlike fossil fuels, it does not produce greenhouse gas emissions, air pollution, or water contamination. The adoption of wind energy in agriculture can contribute to climate change mitigation and environmental sustainability. Agricultural activities powered by renewable energy reduce carbon emissions and promote sustainable farming practices. In addition, wind turbines require relatively small land areas compared to other energy infrastructures. Farmers can continue agricultural activities such as grazing or cultivation around wind turbines.

Economic Benefits for Farmers

The adoption of wind energy can provide several economic advantages to farmers in Western Rajasthan. First, wind energy reduces fuel costs associated with diesel pumps and generators. This leads to significant savings in farm operating expenses. Second, farmers can earn additional income by leasing land for wind turbine installations. Renewable energy companies often rent land from farmers for establishing wind farms, providing them with a steady source of income. Third, decentralized renewable energy systems create employment opportunities in rural areas. Installation, operation, and maintenance of wind energy systems require skilled manpower, which can generate jobs for local youth.

Role in Sustainable Development

Sustainable development involves balancing economic growth, environmental protection, and social welfare. Wind energy contributes to all three aspects of sustainability. From an environmental perspective, wind energy reduces carbon emissions and promotes clean energy production. Economically, it lowers energy costs for farmers and provides new income opportunities. Socially, it improves energy access in remote rural areas and supports rural development. Western Rajasthan's agriculture is highly vulnerable to climate variability. By integrating wind energy with modern agricultural practices, farmers can develop climate-resilient farming systems.

Challenges and Future Prospects

Despite its advantages, wind energy development in Rajasthan faces several challenges. These include high initial investment costs, variability of wind speeds, lack of awareness among farmers, and limited infrastructure for decentralized energy systems. In recent years, renewable energy policies have focused more on solar energy, which has slowed the growth of wind power in the state. Rajasthan currently has about 5 GW of installed wind capacity, even though the state has a much larger potential. However, future strategies are likely to emphasize hybrid solar-wind energy parks and integrated renewable energy systems to improve energy reliability and grid stability.

Government initiatives, research institutions, and agricultural universities can play an important role in promoting wind energy technologies for agriculture. Demonstration projects, farmer training programs, and financial incentives can accelerate adoption.

Conclusion

Wind energy holds immense potential for supporting sustainable agricultural development in Western Rajasthan. The region's favorable wind conditions and vast open land make it suitable for wind energy generation. By utilizing wind energy for irrigation, electricity generation, agricultural processing, and hybrid renewable systems, farmers can reduce energy costs, improve productivity, and enhance resilience to climate change. With appropriate policies, technological innovations, and farmer awareness programs, wind energy can become a key driver of sustainable agriculture in Western Rajasthan. Declaration: The authors claim no originality of the work except for the arrangement and presentation of the subject matter through screening of various reviews from books, journals, websites etc.

References

1. Official website of Ministry of New and Renewable Energy, Govt of India accessed on 21.02.2026 https://mnre.gov.in/

2. Your Story, Press Trust of India https://yourstory.com/2015/11/railways-windmill-jaisalmer accessed on 28.02.2026

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

H.L. Raiger

ICAR-National Bureau of Plant Genetic Resources, New Delhi

N.K. Jajoriya

ICAR-National Bureau of Plant Genetic Resources, New Delhi

ARTICLE ID: 33

Winged Bean [*Psophocorpus tetrogonolobus* (L.) DC.]: A Nutritionally Rich Multi-Purpose legume

Introduction

Winged bean (*Psophocorpus tetrogonolobus* (L.) DC.) is an annual or perennial vine, commonly known as the Dragon bean, Goa bean, Four-angled bean, Four-cornered bean, Manila bean and Cigarrilas. It is herbaceous perennial but mainly grown as annual. It is cultivated in hot and humid countries across Asia. The major cultivating countries are India, Burma, Sri Lanka, Indonesia, Malaysia, Thailand, Phillippines, Indo-China, China and also extended to Papua & New Guinea. The diversity of this crop has been observed in papus, New Guinea, Mauritius and India. In India, it is grown at least in eight states including Assam, Manipur, Mizoram, Kerala, Tamil Nadu and Karnataka by the tribals as a backyard corp. The Wild progenitor of winged bean has remained somewhat enigmatic given the absence of wild Psophocarpus in Asia, leading to one suggestion that the true wild progenitor is now extinct. On morphological basis winged bean *viz. P. scandens* and *P. polustris* in subgenus Psophocaspus, with *P. scangens* the closest wild species to winged bean.

Distribution and Adaptation

Winged bean is regarded as a crop of hot humid tropics. The crop thrives well from sea level to 2000 msl. Winged bean is distributed throughout Asia and West Africa. In India, it is confined to humid sub-tropical parts of North-Eastern region comprising states of Tripura, Manipur, Mizoram, Nagaland and Assam. It also occurs sporadically in ghats of Maharashtra, Karnataka, Kerala and Orissa.

A total of 213 germplasm accessions of Winged bean (Psophocarpus tetragonolobus (L.) Dc.) are present in National Gene Bank (NGB) for long-term conservation. These genetic materials are available to Winged bean breeders for utilization in their breeding programs. Promising accessions for green vegetable also possessed semi-dwarf plant habit, condensed internodes, early flowering (97-105 days), medium long tender pods of pale green of green colour and very good fruiting.

Collections identified for green pods, 4 for fodder, 5 tolerant to frost/cold, 5 photosensitive, 5 have double pod, 7 in tuber yield and 6 as good seed types. Similarily, accessions rich in protein contents white six were indigenous collections *viz.* IC 17004, IC 17006, IC 26944 and IC 26949 and 13 were exotic collections *viz.* EC 27884, EC 38826-1, EC 38955, EC 38957, EC 38957, EC 114273-1, EC 116887, EC 116884, EC 118031 and EC 118345.

Four dual purpose (seed and vegetables) Winged bean varieties were released under the umbrella of All India Coordinated Research Network on Potential crops in India.

1. **AKWB-1:** This variety was developed as a selection from Germplasm accession EC114273. This is dual purpose (seed and vegetable) with high pod yield variety released in 1991 released by NBPGR, Akola, all winged bean growing areas. Its average green pod yield is 105 q/ha and seed yield of 10-12 q/ha. The variety is suitable as vegetable and pulse purpose.
2. **IWB-1:** This variety was developed as a pure line selection from Germplasm village Lakhampur, Ambikapur, Dist. Surguja (Chhattisghar). 'Indira Winged bean-1' dual purpose (seed and vegetable) with high pod yield variety was released by IGKV, Ambikapur in 2016 for Chhattisgarh, Jharkhand and Maharashtra. Its average green pod yield is 115 q/ha and seed yield of 11-13 q/ha.
3. **'Chhattisgarh Chaudhari Sem-2':** This variety was developed as a pure line selection from Germplasm village Laalanpur, Ambikapur, Dist. Surguja (Chhattisghar). This variety is Dual purpose (seed and vegetable) with high pod yield variety was released by IGKV, Ambikapur in 2017 for Chhattisgarh. Its average green pod yield is 124 q/ha and seed yield of 20 q/ha.
4. **IWB-2:** This variety was developed as a pure line selection from Germplasm IC095229. 'Indira Winged bean-2' dual purpose (seed and vegetable) with high pod yield variety was released by IKGV, Ambikapur in 2018 for Chhattisgarh, Jharkhand and Maharashtra. Its average green pod yield is 128 q/ha and seed yield of 19 q/ha.
5. **Phule Shrawani:** This variety was developed as Selection from germplasm EC 142666 received from Akola. The variety is dual purpose (seed and vegetable) with high pod yield variety was released by MPKV, Rahuri in 2023 for Maharashtra, Chhattisgarh, UP, Jharkhand. Its average green pod yield is 135.65 q/ha and seed yield of 13.53 q/ha.
6. **Birsa Kamrenga-1:** This variety was developed as selection from local germplasm (Madhupur, Devghar, Jharkhand). The variety is dual purpose (seed and vegetable) with high pod yield variety was released by BAU, Ranchiin 2023 for Jharkhand. Its average seed yield of 14.29 q/ha.
7. **Phule Chardhariwall:** This variety was developed as selection from local germplasm of Winged bean 2011-2, collected from village Karad Dist. Satara, Maharashtra. The variety is dual purpose (seed and vegetable) with high pod yield variety was released by MPKV, Rahuri in 2021 for Maharashtra, Chhattisgarh, UP, Jharkhand. Its average green pod yield is 130 q/ha.

Promising genotypes and land races available

Apart from the above released variety there are other improved genotypes which have performed well in Indian plains. Based on the average performance tested over locations and years in All India Coordinated Research Network on Underutilized Crops, following genotypes were selected for better pod and seed yield:

EC 178313	:	Average seed yield recorded in AICRP trials 8.84 q/ha with 165 days to maturity.
IC 026945	:	Average seed yield recorded in AICRP trials 8.81 q/ha with 163 days to maturity
EC 142665	**:**	Average seed yield recorded in AICRP trials 8.74 q/ha with 163 days to maturity.
EC 178331	**:**	Average seed yield recorded in AICRP trials 8.41 q/ha with 163 days to maturity.

Dwarf Mutant : Average seed yield recorded in AICRP trials 8.22 q/ha with 161 days to maturity and has been developed at UAS Bengalore

Mysore Local : Average seed yield recorded in AICRP trials 7.69 q/ha with 163 days to maturity and has been developed at UAS Bengalore

Agronomic Management

Hot and humid climate is ideal for the cultivation of winged bean. It can tolerate 15.4 to 27.5 °C temperature and 700-4100 mm annual rainfall. However, a temperature range of 20-30 °C is optimum for its growth, flowering and fruiting. Day temperature of 30 °C and night temperature of 22 °C is most favourable for vegetative growth. Flowering is observed from mid-September to October when short day condition prevails. The crop grows well up to an elevation of 2000 m.

Preparation of land

Prepare the land by ploughing followed by levelling. Well rotten FYM is mixed with soil in the trenches.

1. **Soil:** Sandy to heavy clays, well-drained sandy loam.
2. **FYM:** 8-10 t/ha or Vermi-compost 5 t/ha, 10-15 days before sowing followed by ploughing & levelling.
3. **Fertilizer Dost:** N:P:K::50:80:50. Half dose of nitrogen (25N), full dose of phosphorus (80P) and Potash (50K) (if needed) at the time of sowing. Remaining nitrogen (25N) applied after 40-60 days of sowing after weeding of crop.
4. **Time of Planting:** June-July
5. **Seed Rate:** 15-20kg/ha pre-soak for one to two days; Seed depth:3-4cm
6. **Spacing:** Line Sowing With plant of plant: 45cm and row to row: 60cm.
7. **Seed germinates** within 5 to 7 days after sowing and needs maximum care till it attains a height of about 25-30 cm. After establishment of stand, its maintenance is easy.
8. **Weed Control:** one hand weeding 15-20 DAS is required to control weeds during early growth period.
9. **Staking:** Staking is very important practice to obtain good and quality yield due to indeterminate stem growth.

Water management

The first irrigation is given immediately after sowing. Avoid rapid water flow to prevent washing off of seeds. Irrigations shall be given at frequent intervals except on rainy days. Proper drainage of water should be ensured to avoid occurrence of diseases and pests.

Inter-cultural Operation: First hand weeding should be done 15-20 days after sowing and second 35-40 days after sowing for the management of the weed. Later the broad leaves helps not to allows weeds to survive. If green manure crop is grown, weeding operations can be reduced.

Harvesting & Storage: Green pods can be harvested at tender stage from about 10 weeks after sowing. Winged bean can be stored in a plastic bag tightly tied at the neck to keep them fresh. The shelf life of the pods can be increased to 4 weeks under storage temperature of 10 °C and the 90% relative humidity. Dry grains for 2-3 weeks up to 11-13% moisture content and stored in iron drums or earthen pots.

Yield: In India, yields reported from experimental plots are of the order of 7 – 15 q/ha for seed, 40 – 95 q/ha for green pods and 48 – 60 q/ha for tubers. There is an ample scope of improvement in yields by use of improved cultivation practices.

Diseases and Insects

There are no major reports of incidence if disease and insect-pest on winged bean in India. However, false rust (Synchytrium psophocarpi), leaf spot (*Pseudocercospora Psophocarpi*) are the important fungal diseases. Similarly, *Maruca testulalalis* and *Hermoceplachna signatipennis* and root knot nematodes may affect the crop.

Therefore, suitable plant protection measures may be taken to minimize yield losses.

Nutritional significance

Winged bean has been recognized as a crop having much promise for nutritional security in the coming decades. Winged bean tubers are notably rich sources of starch, protein, and B-complex, Vitamine C. Winged beans provide adequate amounts of protein minerals, and vitamins. In addition, Thiamine, phridoxine (vitamin B-6), niacin, and riboflavin are some of the B-complex vitamins embedded in these beans. Some of the essential minerals such as iron, copper, manganese, calcium, phosphorus, magnesium are concentrated in them. Green leaves of Winged bean are an excellent source of fiber, vitamin-C, Vitamin-A, and minerals.

Table 1. Nutritive value (per 100g) of underutilized and major food legumes

Crop	Crude protein (g)	Fat (g)	Carbo-hydrate (g)	Fiber (g)	Ash (g)
Rice bean	20.9	0.9	60.7	4.8	4.2
Faba bean	26.2	1.3	59.4	6.8	3
Adzukibean	19.9	0.6	64.4	7.8	4.3
Winged bean	32.8	17.0	36.5	4.1	3.6
Chick pea	19.4	5.6	60.9	2.5	3.1
Pigen pea	21.6	1.4	72.7	8.1	4.2

It has been observed that proteins present in legumes have low nutritive value which is mainly attributed to low amounts of Sulphur-containing amino acids, less digestible proteins and anti-nutritional factors. The cause of low digestibility of proteins is referred to the presence of protease (trypsin and chymotrypsin) inhibitors and tannins. The presence of trypsin inhibitor, hemagglutinin, tannins and phytic acid in winged bean seeds is well substantiated. Combined and possibly synergistic effect of all these factors are responsible for the toxicity of raw winged bean. To eliminate the negative effect of these anti-nutritional factors, to reduce certain anti-nutrients, to improve the nutritional quality it can be destroyed by cooking. The amino acid content of immature pods was generally lower, whereas, the non-protein nitrogen content was higher. The digestibility is lowest (72.8%) compared with other legumes.

Future thrust and prospects

While past research was limited by poor infrastructure, recent advances in genomics, transcriptome sequencing, and tissue culture now allow scientists to improve the crop by comparing it to established legumes like soybean. Future breeding aims to eliminate anti-nutritional factors (like tannins) and improve the plant's sensitivity to cold, waterlogging, and specific light cycles (photosensitivity). Often called the "forgotten vegetable," it is a powerhouse of nutrition that can combat malnutrition and provide a stable income for resource-poor farmers in marginal upland areas. The crop is hardy enough to withstand adverse climate changes, making it a vital tool for future food security. To turn this local legume into a crop of worldwide impact, there is an urgent need for germplasm conservation, increased public awareness, and supportive government funding and policy.

Just Agriculture Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

Samyuktha S S
Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore - 641003, Tamil Nadu, India.

Vishnu M
Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore - 641003, Tamil Nadu, India.

Dinesh Kumar S
Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore - 641003, Tamil Nadu, India.

Kannan M
Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore - 641003, Tamil Nadu, India.

ARTICLE ID: 34

NANOPARTICLE SYNTHESIS: FROM ATOMIC BUILDING BLOCKS TO NANOSCALE MATERIALS

Abstract

Nanotechnology deals with materials that are incredibly small but powerful enough to transform major fields of science. A key part of nanotechnology is understanding how nanoparticles are synthesized because their size, shape and purity determine the behaviour and the place of utility of the material. Nanoparticle synthesis generally follows two main approaches: building them from atoms (bottom-up) or breaking larger materials into nano-sized particles (top-down). This article explains the major chemical, physical, and biological methods used for nanoparticle production, highlighting how each technique works, its advantages, and its applications. By exploring these methods, readers gain a clearer picture of how tiny particles create big opportunities in science and technology.

Keywords: Nanoparticle synthesis, chemical method, physical method, green synthesis, top down approach, bottom up approach

Introduction

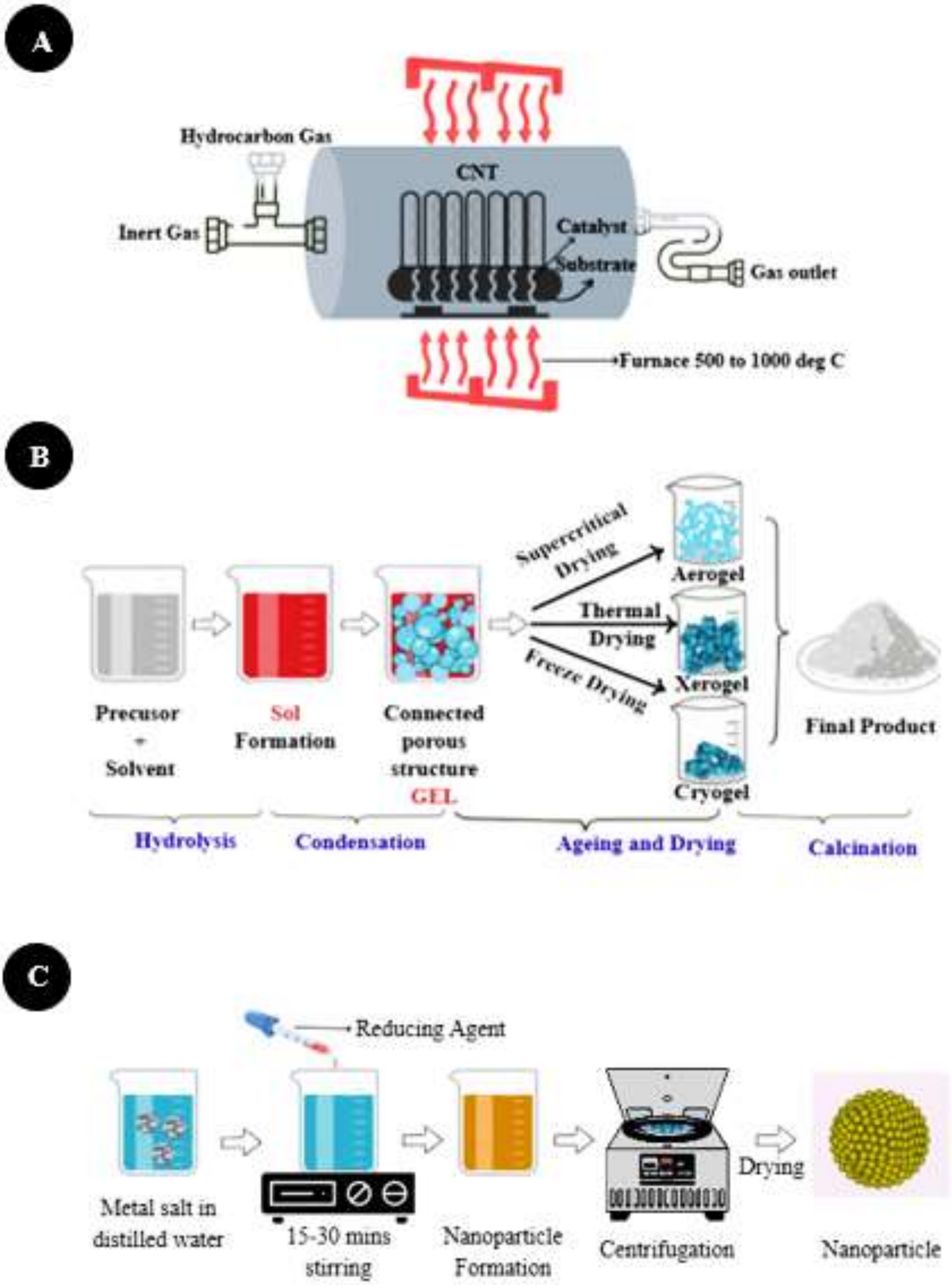
Nanotechnology is one of the most rapidly advancing fields in modern science, influencing medicine, agriculture, engineering, physics, electronics and environmental science. Tiny things are said to have great impact and nanoparticles are the perfect example of it. These materials measure between 1 to 100 nanometers, possessing unique physical, chemical, and biological properties making them more reactive and efficient that their larger counterparts. Thus nanoscale increases surface area, enhance reactivity and improves their performance across various applications. Understanding how these nanoparticles are synthesized is crucial for developing advanced technologies. Their synthesis falls under three major categories; chemical, physical and biological methods. These methods also fit into two fundamental strategies: bottom-up approaches (constructive) that build particles atom-by-atom and top-down approaches (destructive) that break bulk materials into nanoscale particles.

Chemical Methods

Chemical approaches are among the most common and versatile strategies. They generally rely on controlled reactions to produce nanoparticles with precise size and shape. Popular chemical methods include: chemical vapour deposition (CVD), sol–gel synthesis, thermal decomposition, laser pyrolysis, chemical reduction and co-precipitation. These techniques are widely used because they allow excellent control over the composition and uniformity of the nanoparticles.

- **Chemical vapour deposition (CVD)**

CVD is a method in which a thin film of nanoparticles is deposited onto a substrate inside a reaction chamber. Reactant gases are introduced into the chamber, which is heated to around 500–1000°C, causing chemical reactions that lead to the formation and deposition of a uniform, highly pure and strong nanoparticle film. However, the process is expensive due to the specialized equipment required, and it generates toxic gaseous by-products.


A
Hydrocarbon Gas
CNT
Inert Gas
Catalyst
Substrate
Gas outlet
Furnace 500 to 1000 deg C
B
Supercritical Drying
Thermal Drying
Freeze Drying
Aerogel
Xerogel
Cryogel
Final Product
Precusor + Solvent
Sol Formation
Connected porous structure
GEL
Hydrolysis
Condensation
Ageing and Drying
Calcination
C
Reducing Agent
Metal salt in distilled water
15-30 mins stirring
Nanoparticle Formation
Centrifugation
Drying
Nanoparticle

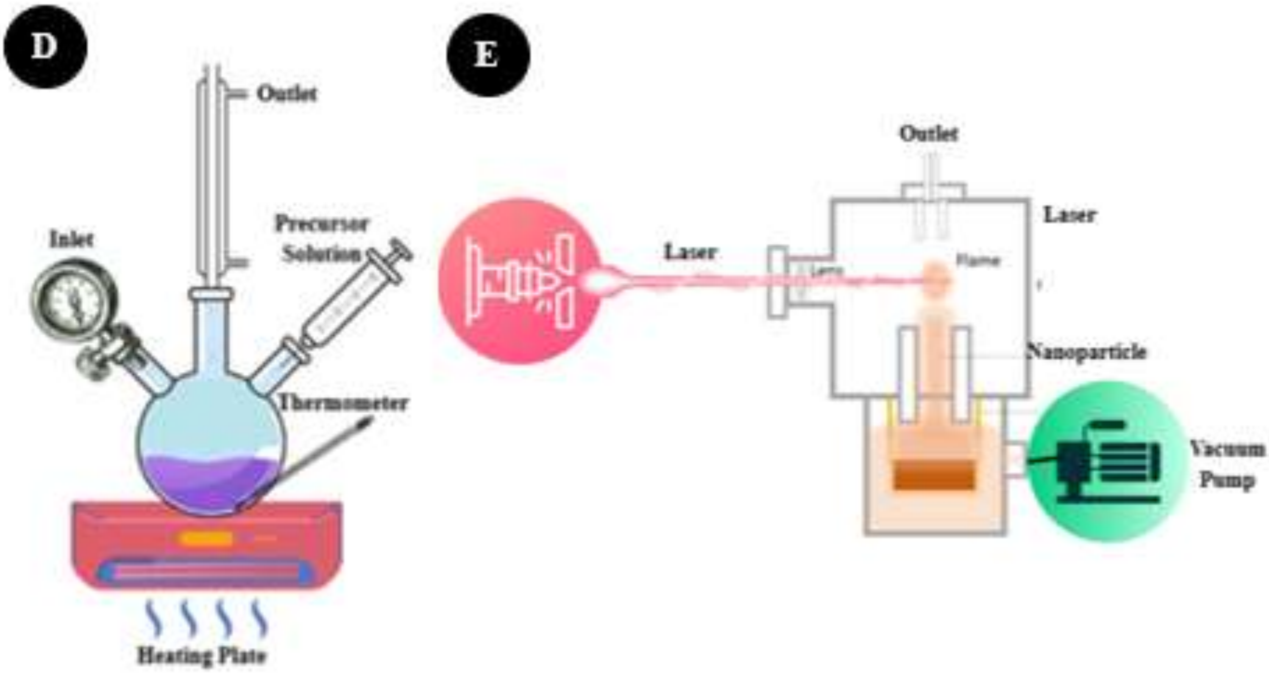
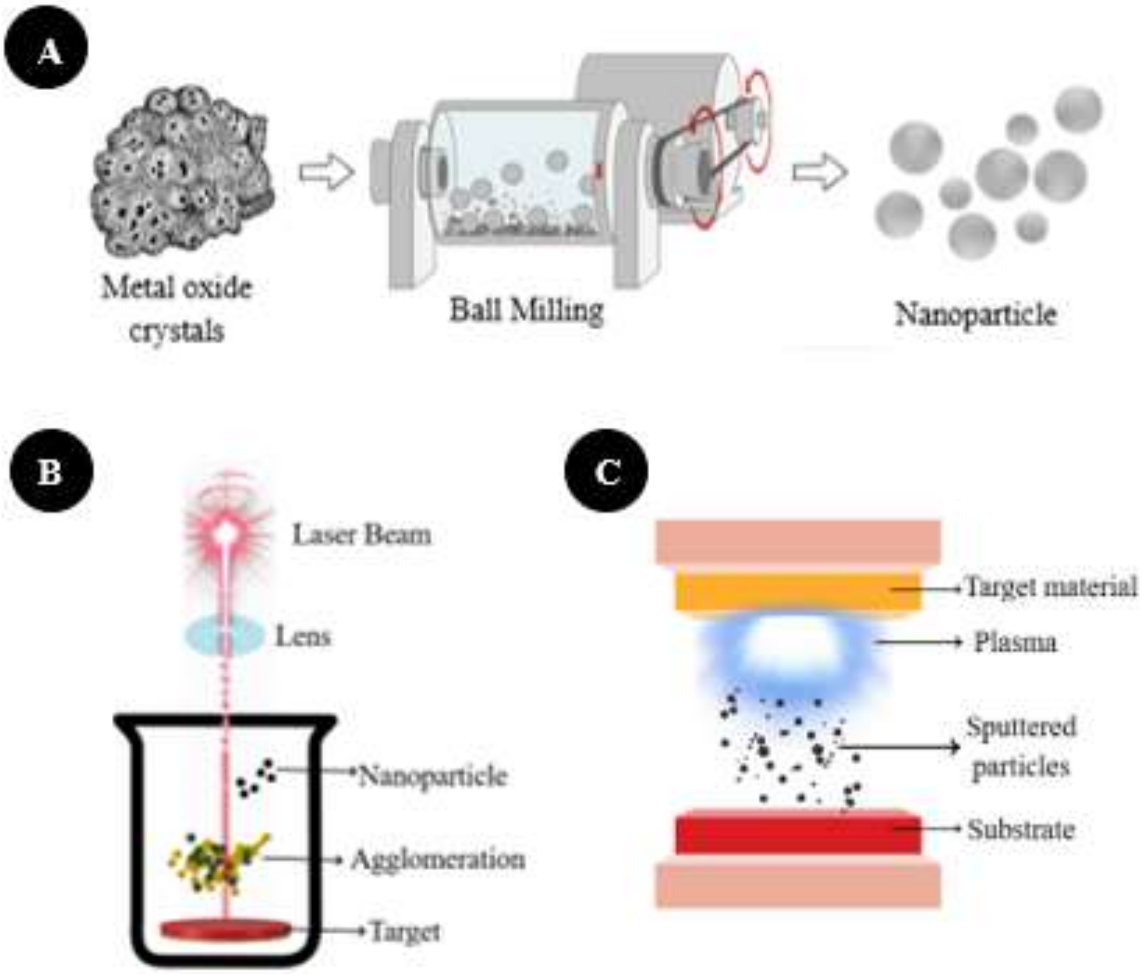


Figure 1: Chemical Method A) Chemical Vapour Deposition B) Sol gel Formation C) Chemical Reduction D) Thermal Deposition E) Laser Pyrolysis



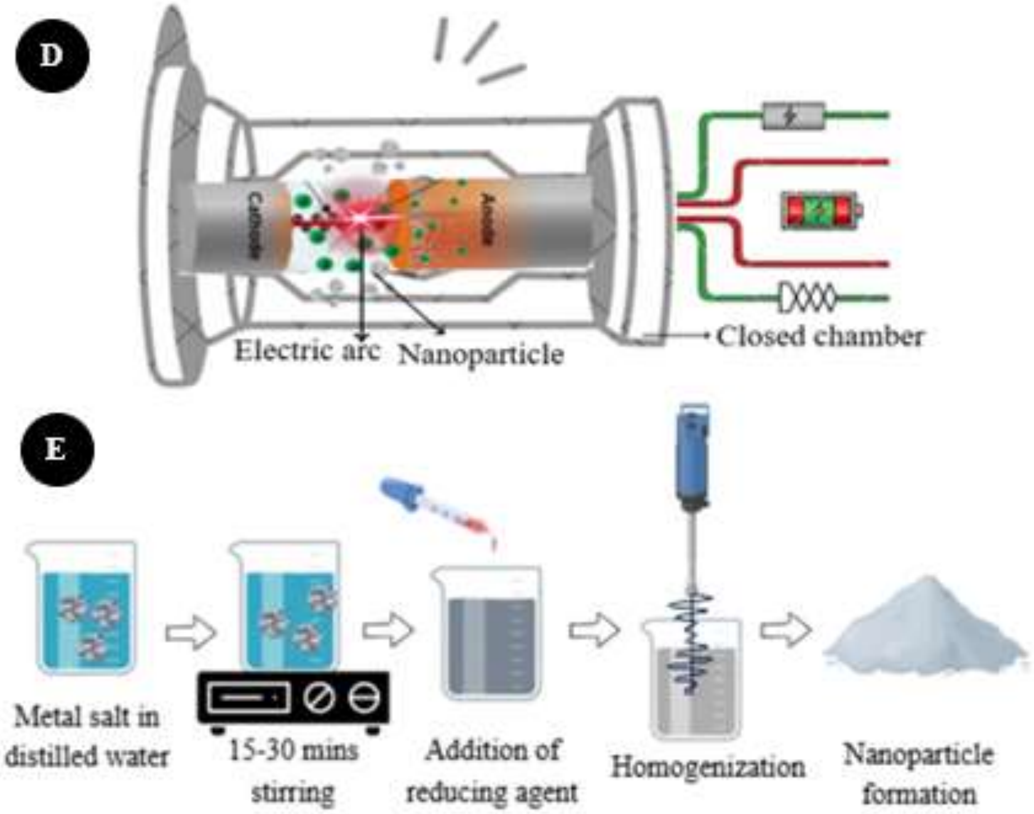


Figure 2: Physical Method A) Ball Milling B) Laser Abalation C) Sputtering D) Arc Discharge E) Ultrasonication

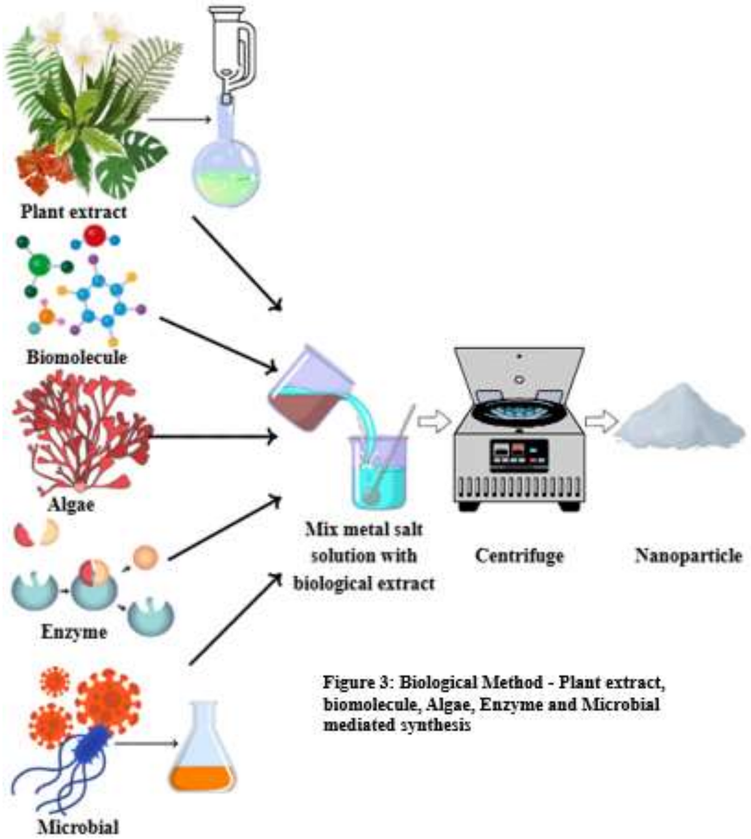


Figure 3: Biological Method - Plant extract, biomolecule, Algae, Enzyme and Microbial mediated synthesis

- **Sol–gel synthesis**

Sol–gel synthesis is a wet chemical process. A chemical precursor (metal oxides or metal chlorides) is dispersed in a host liquid by shaking, stirring or sonication to form a sol, a mixture containing both liquid and solid phases. The sol then undergoes phase separation to form a gel, which is a solid macromolecular network within a solvent. Depending on the drying method, the gel can be converted into an aerogel (supercritical drying), xerogel (thermal drying) or cryogel (freeze drying). Finally, calcination of the dried gel yields nanoparticles. This versatile method allows the synthesis of a wide variety of nanoparticles.

- **Thermal decomposition**

Thermal decomposition involves heating metal–organic precursors with surfactants in high-boiling organic solvents, where the applied heat breaks the precursors into metal atoms that nucleate and grow into uniform, monodisperse nanoparticles. The temperature at which decomposition occurs is specific to each material, and the process often results in the formation of secondary products alongside the nanoparticles. This method is widely used for producing highly crystalline nanoparticles with excellent size and shape control which is ideal for magnetic materials, catalysis, biomedical imaging, and electronic applications.

- **Laser pyrolysis**

For large-scale production of nanoparticles, pyrolysis is commonly used, where the precursor (in liquid or vapour form) is burned inside a high-temperature furnace. The combustion breaks down the precursor and generates nanoparticles as the by-product. Advanced pyrolysis techniques use lasers or plasma to achieve the required high temperatures. This method is simple, efficient, cost-effective and suitable for continuous, high-yield nanoparticle production.

- **Chemical reduction**

In the chemical reduction method, metal ions from a precursor salt are converted into neutral metal atoms using a reducing agent. These atoms then come together to form nanoparticles. A stabilizer is usually added to prevent clumping and to help control the size and shape of the particles. By adjusting factors like temperature, concentration, and mixing speed, the properties of the nanoparticles can be precisely tuned.

- **Co-precipitation**

In co-precipitation method precipitating agent is added, which bring metal ions together forming solid nanoparticles. As the pH rises, the ions react and form insoluble metal hydroxides or oxides, which then grow into nanoparticles. The process is usually left stirring or added with stabilizers to prevent clumping. By controlling pH, temperature and ion concentration, uniform nanoparticles can be produced easily, making co-precipitation a simple and fast method.

Physical Methods

Physical methods focus on breaking down bulk materials into nanoscale particles or using physical forces to generate them. Major physical techniques include: ball milling, laser ablation, evaporation and condensation, arc discharge, sputtering and ultra-sonication. These methods are useful when nanoparticles cannot be easily produced through chemical methods.

- **Ball milling**

In ball milling, the precursor material (bulk powder) and the hardened milling balls are loaded into a sealed milling chamber, where parameters such as speed, time, ball-to-powder ratio and inert gas are adjusted. As the mill rotates, high-energy impact and shear forces cause repeated collisions between the balls and powder. Therefore, repeated collision gradually breaks the bulk powder into nano particles. This method offers a simple, solvent-free, low-cost method useful for preparing alloys, composites, and fine powders.

- **Laser ablation**

Laser ablation involves striking a metal target immersed in a liquid with a high-energy laser beam, generating a plasma plume that leads to nanoparticle formation. Since no stabilizers or chemical reagents are needed, this method is viewed as a green and eco-friendly alternative. It is a technique that produces stable nanoparticles in both water and organic solvents.

- **Evaporation and condensation**

Evaporation-condensation method involves heating a metal in high temperature furnace until it evaporates, and then the vapour is allowed to cool and condense the content into nanoparticles inside an inert gas atmosphere. This physical, chemical-free process produces highly pure nanoparticles with controlled size by adjusting parameters.

- **Arc discharge**

In the arc discharge method, two electrodes of the target material are placed close together and a high electric current is passed between them, creating an intense arc that vaporizes the material; the vapour then cools and condenses into nanoparticles. This method produces highly crystalline nanoparticles and is widely used due to its simplicity and ability to generate high-quality products like carbon nanotubes.

- **Sputtering**

Sputtering produces nanoparticles by bombarding a target material with high-energy ions, causing atoms to be ejected and deposited as a thin nanoparticle layer on a substrate. The deposited film is often annealed afterward to enhance its structural and functional properties. Factors such as film thickness, annealing temperature and duration, and the nature of the substrate play key roles in determining the final size and shape of the nanoparticles.

- **Ultra-sonication**

In ultrasonication, the precursor is first dissolved in an appropriate solvent. A reducing or stabilizing agent may be added to control particle size. The mixture is then exposed to an ultrasonic bath or probe sonicator, where ultrasonic waves break down the precursor through cavitation, leading to the nucleation and formation of nanoparticles.

Biological Methods

Biological method is known as green synthesis; biological approaches use natural sources to produce nanoparticles in an eco-friendly manner. These methods employ: plant extracts, microorganisms, algae, biomolecules and enzymes. In the biological method, the overall process remains similar, while only the source of the biological reducing agent differs.

After source preparation, a metal ion solution is prepared and mixed with the biological extract. The biomolecules present in the source act as natural reducing and capping agents, converting metal ions into nanoparticles, usually indicated by a characteristic colour change depending on the material. The reaction mixture is then incubated, followed by centrifuged washed and dried to obtain purified nanoparticles.

Conclusion

Nanoparticle synthesis is fundamental to the advancement of nanotechnology, as the method of preparation directly influences particle size, morphology, stability, and functional performance.

Chemical methods provide precision, physical methods offer high purity, and biological approaches introduce sustainability and eco-friendliness. Each technique has distinct advantages and limitations, and selecting the appropriate method depends on the required application and material properties. As research progresses, the focus is shifting toward greener, scalable, and more efficient synthesis routes that balance performance with environmental responsibility, paving the way for broader and safer applications of nanoparticles across diverse fields.

References

- Rane, A. V., Kanny, K., Abitha, V. K., & Thomas, S. (2018). Methods for synthesis of nanoparticles and fabrication of nanocomposites. In *Synthesis of inorganic nanomaterials* (pp. 121-139). Woodhead publishing. https://doi.org/10.1016/B978-0-08-101975-7.00005-1
- Rao, B. G., Mukherjee, D., & Reddy, B. M. (2017). Novel approaches for preparation of nanoparticles. In *Nanostructures for novel therapy* (pp. 1-36). Elsevier. https://doi.org/10.1016/B978-0-323-46142-9.00001-3
- Dhand, C., Dwivedi, N., Loh, X. J., Ying, A. N. J., Verma, N. K., Beuerman, R. W., ... & Ramakrishna, S. (2015). Methods and strategies for the synthesis of diverse nanoparticles and their applications: a comprehensive overview. *Rsc Advances*, *5*(127), 105003-105037 DOI: 10.1039/C5RA19388E

Just Agriculture
Multidisciplinary
e- newsletter

e-ISSN: 2582-8223

Volume - 6
Issue - 8
April, 2026

www.justagriculture.in

AUTHORS' DETAILS:

HEMANT

Master of Social Work (MSW), Chaudhary Charan Singh University, Meerut (U.P.)

ARTICLE ID: 35

A Study on Bullying, Psychological Distress and Dropout Intentions among LGBTQAI Adolescents in Secondary Education

Abstract

LGBTQAI+ (lesbian, gay, bisexual, transgender, queer, asexual, intersex and other) adolescents in secondary schools face disproportionately high rates of bullying, which contributes to elevated psychological distress and intentions to drop out. This article synthesizes existing research on the pathways from bullying victimization to psychological distress and school disengagement among LGBTQAI+ youth. It proposes school social workers as key moderators who can interrupt these pathways through targeted interventions, climate improvement and supportive services. Drawing on national surveys and empirical studies, the review highlights how affirming school environments and professional support from social workers can mitigate risks. Implications for policy, practice, and future research in secondary education settings are discussed. Keywords: LGBTQAI+ adolescents, bullying, psychological distress, school dropout, school social workers, moderation.

Introduction

Secondary school represents a critical developmental period for adolescents, yet for LGBTQAI+ youth, it is often marked by heightened vulnerability to peer victimization. Bullying—encompassing physical, verbal, social, and cyber forms—targeted at sexual orientation, gender identity or expression remains pervasive.

Figure 1. Inclusive secondary school classroom environment promoting diversity and belonging (representative of affirming spaces that can buffer risks).

National data indicate that approximately 52% of LGBTQ youth in middle and high schools experience bullying (in-person or electronic) within a single year, with rates climbing to 65% among middle school students and 61% among transgender and nonbinary youth. These experiences are not isolated incidents but chronic stressors that fuel psychological distress, including depression, anxiety, and suicidal ideation, ultimately contributing to dropout intentions and truancy.

Research consistently shows LGBTQAI+ adolescents report bullying at rates far exceeding their cisgender heterosexual peers, with bias-based harassment exacerbating academic disengagement. Psychological distress acts as a mediator: repeated victimization erodes self-esteem and emotional regulation, leading to avoidance behaviors such as skipping classes or contemplating leaving school altogether. Dropout intentions, in turn, predict actual disengagement, perpetuating cycles of marginalization and long-term socioeconomic disadvantage.

This article examines these interconnected phenomena and advances a conceptual model positing school social workers as critical moderators. By providing direct counseling, advocating for inclusive policies, facilitating peer support networks, and training staff, school social workers can weaken the link between bullying and its adverse outcomes. The analysis is grounded in secondary school contexts, where adolescents spend the majority of their waking hours and where interventions can yield immediate protective effects.

Literature Review Bullying Victimization among LGBTQAI+ Adolescents

Bullying in secondary schools targeting LGBTQAI+ youth is often bias-driven, involving homophobic or transphobic slurs, exclusion, physical aggression, and online harassment. Studies document that 33% of LGBTQ youth experience in-person bullying and 42% electronic bullying annually, with transgender/nonbinary students and middle schoolers disproportionately affected. Bias-based bullying produces stronger negative effects than general victimization, including heightened internalizing problems (e.g., depression, anxiety) and externalizing risks (e.g., substance use).

Psychological Distress as a Mediator

Psychological distress—manifested as anxiety, depression, low self-worth, and suicidal ideation—serves as a primary mechanism linking bullying to school-related outcomes. LGBTQ youth who are bullied show three times greater odds of suicide attempts compared to non-bullied peers. Among bullied middle schoolers, 29% reported past-year suicide attempts versus 12% of non-bullied counterparts. Mediation analyses confirm that distress transmits the effects of physical/sexual harassment to truancy, regardless of additional structural risks like homelessness. This pathway is particularly pronounced in secondary schools, where academic pressures compound emotional strain.

Dropout Intentions and School Disengagement

Chronic bullying and resulting distress elevate dropout intentions through mechanisms such as fear-based absenteeism, lowered academic motivation, and perceived lack of safety. LGBTQAI+ students report higher rates of skipping classes, lower GPAs, and reduced postsecondary aspirations. Global and U.S. data link victimization to increased likelihood of leaving school entirely, with one-third of transgender youth considering dropout due to safety concerns.

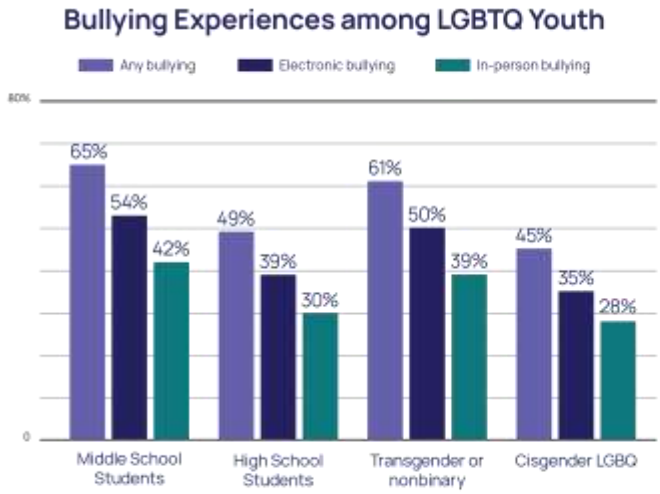


Figure 2. Bullying experiences among LGBTQ youth by school level and identity (data visualization highlighting disparities in secondary education).

The Moderating Role of School Social Workers

School social workers occupy a unique position as mental health liaisons, advocates, and systems coordinators within secondary schools. Emerging evidence suggests that supportive school personnel—including social workers—moderate the bullying-distress-dropout pathway by fostering positive school climates and providing targeted interventions. Positive climate (characterized by low homophobic teasing and high acceptance) significantly attenuates differences in depression/suicidality, substance use, and truancy between LGBTQAI+ and heterosexual youth. In supportive climates, outcomes for LGBTQAI+ students converge toward those of their peers.

School social workers operationalize this moderation through:

1. **Direct Clinical Support**: Individual and group counseling to build coping skills, reduce distress, and process victimization.
2. **Climate-Building Initiatives**: Facilitating Gender and Sexuality Alliances (GSAs), staff training on LGBTQAI+ competency, and policy advocacy against bias-based bullying.
3. **Systems Coordination**: Linking students to external resources, collaborating with teachers/administrators, and monitoring intervention efficacy.

Affirming environments—supported by social workers—reduce bullying odds by 30% and lower suicide risk. Where social workers are actively involved, students report greater safety, fewer absences, and stronger school connectedness, disrupting the mediation chain from victimization to distress and disengagement.

Figure 3. Supportive group counseling environment for LGBTQAI+ youth (illustrating the role of affirming adult facilitation in secondary schools).

Proposed Conceptual Model

The model posits: Bullying Victimization → Psychological Distress → Dropout Intentions School Social Worker Interventions (e.g., counseling, climate enhancement) moderate both the bullying-distress link (by buffering immediate emotional impact) and the distress-dropout link (by promoting resilience and re-engagement).

Empirical support derives from moderation analyses showing school climate and supportive staff reduce outcome disparities. Future quantitative studies could test this via structural equation modeling in secondary school samples, measuring social worker caseload involvement as a moderator variable.

Implications for Secondary Schools

- **Policy**: Mandate LGBTQAI+-inclusive anti-bullying policies and dedicated social worker positions in every secondary school.
- **Practice**: Integrate social workers into multi-tiered systems of support (universal prevention via GSAs; targeted counseling; intensive crisis response).
- **Training**: Require ongoing professional development for social workers and all staff on culturally responsive LGBTQAI+ support.
- **Research**: Longitudinal studies tracking moderation effects pre- and post-intervention.

Figure 4. Diverse secondary school students in supportive peer interactions (highlighting the protective potential of inclusive environments fostered by school social workers).

Conclusion

Bullying remains a potent risk factor for psychological distress and dropout intentions among LGBTQAI+ adolescents in secondary schools. However, school social workers represent a powerful, underutilized moderator capable of transforming hostile environments into affirming ones. By investing in their role—through resources, training, and integration into school systems—educators and policymakers can interrupt harmful pathways and promote equitable outcomes. Creating safe, inclusive secondary schools is not only a moral imperative but a practical strategy for fostering the well-being and academic success of all students.

References

- Birkett, M., et al. (2009). LGB and questioning students in schools... *Journal of Youth and Adolescence*.
- GLSEN/Trevor Project data syntheses on bullying and affirming schools.
- Lim, G., et al. (2025). Psychological distress mediates... *Journal of LGBT Youth*.
- Additional sources from national surveys and meta-analyses on school climate and supportive personnel.