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AUTHORS' DETAILS:

**Sweekruta Mohapatra^a,
Sushmita Munda^{*b},
Sanjay K. Dwivedi^c,
B. Raghavendra Goud^d**

^aPh.D scholar, Department of
Agronomy, Indira Gandhi Krishi
Vishwavidyalaya, Raipur,
Chhattisgarh;

^bSenior Scientist, Crop
Production Division, ICAR-
Central Rice Research Institute,
Cuttack, Odisha;

^cPrincipal Scientist, Department
of Agronomy, Indira Gandhi
Krishi Vishwavidyalaya, Raipur,
Chhattisgarh;

^dScientist, Crop Production
Division, Indian Council of
Agricultural Research, Central
Rice Research Institute, Cuttack,
Odisha

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Navigating the Superweed Challenge: Implications for Glyphosate-Resistant Crops

Abstract

Genetically engineered glyphosate-resistant (GR) crops are specially developed to survive the herbicide glyphosate, while most other plants, including weeds, are killed by it. The application of glyphosate in GR crops have transformed weed management in many countries. Over the years, heavy dependence on glyphosate has imposed strong selection pressure on weed populations, accelerating the unintended evolution of glyphosate-resistant weeds, often referred to as “superweeds”. This article examines glyphosate resistance as a double-edged technological advancement, considering both its benefits and unintended consequences. It seeks to determine whether the emergence of so-called “superweed” can be directly attributed to glyphosate use and clarifies the inappropriate application of the term “superweed” to species such as *Lolium rigidum*, *Amaranthus palmeri*, and *Echinochloa crus-galli*. It analyzes the “superweeds” in relation to multiple herbicide modes of action, declining glyphosate efficacy, rising costs, and environmental concerns, and emphasizes the need for integrated weed management to ensure long-term agricultural sustainability.

Keywords: Glyphosate, GR crops, Herbicide resistance, Integrated Weed Management

The widespread adoption of glyphosate is closely linked to the development of glyphosate-resistant (GR) crops. GR crops fundamentally transformed weed management in modern agriculture. The compatibility of glyphosate with GR cropping systems enabled effective weed control through no-till and conservation tillage practices, reducing dependence on conventional mechanical tillage. This shift not only enhanced operational flexibility for farmers but also contributed to improved crop productivity. Several studies have reported yield advantages associated with glyphosate-based weed management, including an average 5.8% increase in maize yields and comparable benefits in oilseed rape, wheat, and barley. Conversely, projections suggest that the absence of glyphosate-based weed control could result in yield reductions ranging from 7-14% in maize, 8-18% in wheat, 8-19% in barley, and 8-22% in oilseed rape.

Despite these agronomic advantages, glyphosate is inherently non-selective and historically was confined to non-crop and orchard systems due to its phytotoxicity to crops. Advances in molecular biology enabled the transfer of glyphosate-insensitive genes into crop species, allowing in-crop applications and leading to a new era of weed management. Today, glyphosate resistance has been incorporated into several major crops, including soybean, maize, canola, and cotton, cultivated across expanding global acreage. However, this unprecedented reliance on a single herbicide has simultaneously laid the foundation for the emergence of glyphosate-resistant weeds, posing a growing challenge to the long-term sustainability of GR cropping systems.

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Glyphosate and the Emergence of Glyphosate-Resistant Crops

Glyphosate [N-(phosphonomethyl) glycine], was first launched by Monsanto in 1974 as Roundup. Glyphosate is an organophosphate molecule that contains the functional groups viz., carboxylic acid group [-COOH], phosphonic acid group [PO₃H₂], and amino group [-NH₂]. Glyphosate interferes with the shikimate pathway which is a crucial metabolic route in plants responsible for the biosynthesis of essential aromatic amino acids. It inhibits the enzyme 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase, thereby blocking the synthesis of tryptophan, phenylalanine and tyrosine in plant cells. It is a non-selective, broad-spectrum herbicide that targets a diverse array of weeds, including perennial, annual broadleaf and grassy weeds.

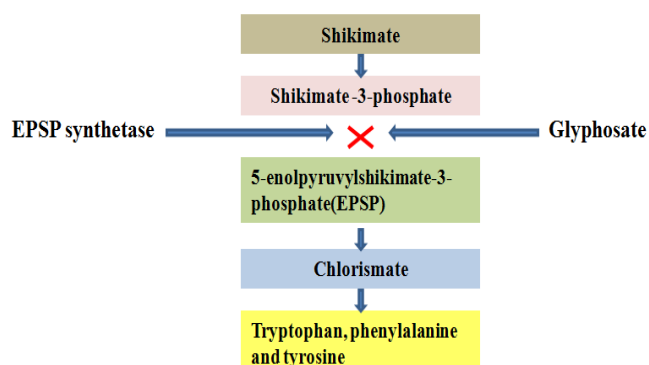


Fig 1. The Shikimate pathway

Glyphosate inhibits the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) in the shikimate pathway, thereby blocking the synthesis of essential aromatic amino acids required for plant growth. Glyphosate resistance is primarily achieved through genetic engineering approaches such as the introduction of a glyphosate-insensitive EPSPS gene (e.g., CP4-EPSPS from *Agrobacterium* spp.), which continues to function even in the presence of glyphosate. Additional strategies include over expression or amplification of EPSPS to outcompete glyphosate inhibition, and glyphosate detoxification mechanisms that convert the herbicide into non-toxic metabolites like aminomethylphosphonic acid (AMPA). Together, these modifications allow GR crops to survive glyphosate application while susceptible weeds are controlled.

Glyphosate gained widespread adoption after the development of GR crops in the 1990s. It now represents over 72% of worldwide pesticide consumption. It is the major weed-management system employed in soybeans, maize, cotton and canola globally. This technology revolutionized modern agriculture, particularly in managing weeds that threaten crop yields. However, this progress has also led to unintended consequences, primarily the emergence of GR weeds, colloquially referred to as "superweeds." This phenomenon has raised significant concerns among agricultural scientists, policymakers and farmers alike, prompting a critical examination of weed management practices in countries such as Argentina, Brazil and the USA, where the cultivation of GR corn and soybean has increased dramatically. Thus, the technological shift that promised simplified weed control, due to its improper usage has resulted in excessive dosages and more frequent applications than recommended leading to rising costs of production and deteriorating the environment by contaminating the soil and water. Consequently, numerous weed species have developed resistance to glyphosate, diminishing the efficacy of this once-revolutionary technology. Since the first identification of glyphosate-resistant *Lolium rigidum* in 1996, an alarming total of 43 weed species exhibiting glyphosate resistance have been documented.

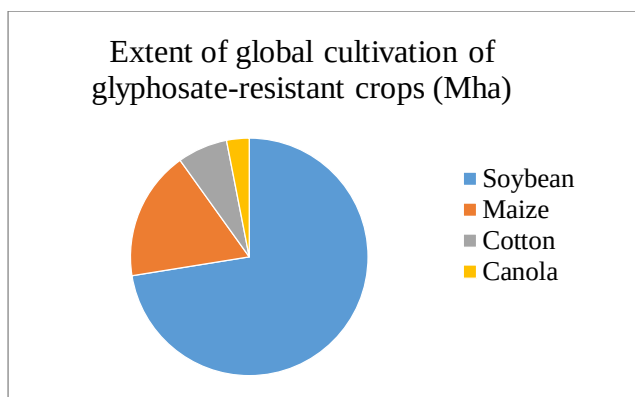


Fig 2. Distribution of GR crops globally

Superweeds Unmasked: Beyond the Sensationalism

The term "superweed" is often used in both scientific and media contexts, but its precise definition remains contentious. Technically 'superweed' is defined as a hybrid plant that contains herbicide resistance genes occurred after random crossing of a genetically engineered crop with a wild plant rendering them problematic and eventually turning them into troublesome weeds. According to the Weed Science Society of America (WSSA), "superweeds" are not formally defined; instead, they refer to herbicide-resistant weeds that display characteristics enabling them to outcompete other plants in multiple ways. While the media frequently sensationalizes the term, portraying resistant weeds as having superhero-like resilience, the reality is more nuanced. The interchanging use of "superweed" with "herbicide resistance" often oversimplifies the complex evolutionary processes that cause weed adaptation. Although herbicide resistance and superweeds have been studied for a long time, but a deeper comprehension of their molecular processes, historical background and nomenclature is essential for accurately characterizing and researching this phenomenon just like it is for any other scientific problem. From a technical perspective, herbicide resistance is defined as "the inherited ability of a plant to survive and reproduce after being exposed to a dose of herbicide that would normally be lethal to the wild type." This process is evolutionary and over reliance on glyphosate creates selective pressure that favors the survival of resistant biotypes within a weed

population. Notably, herbicides do not induce mutations, instead they select for pre-existing genetic variations that confer resistance. As a result, some plants may possess traits that allow them to withstand herbicide applications, ultimately leading to the proliferation of resistant populations. The emergence of superweeds complicates the strategies traditionally employed for weed management. While herbicide rotation is a commonly recommended practice to mitigate resistance, its application is often impractical for superweeds. GR crops are specifically engineered to tolerate glyphosate, and applying alternative herbicides can adversely affect these crops. Consequently, the management options available for superweeds are often more limited than for other resistant weeds, particularly as many superweeds exhibit resistance to multiple modes of action (MOAs). Hence, it is anticipated that superweeds will soon become resistant to commonly used herbicides, thereby posing a significant threat to crop yields.

Debating GE Crops and superweeds: Cause or Effect?

Critics of genetically engineered (GE) crops argue that the rise of superweeds is a direct consequence of intensive agricultural practices and reliance on single herbicide applications. This view advocates that weed resistance is not merely an isolated occurrence but rather a systemic issue arising from monoculture and input-intensive farming systems. As such, critics call for increased regulation and monitoring of GE crops and the associated herbicides to address this growing problem. Conversely, proponents of GE crops tend to frame the emergence of superweeds as a natural aspect of weed biology and evolution, asserting that weed resistance is a normal occurrence in nature. They often downplay the role of glyphosate resistance, suggesting that the issue arises largely from individual farmer practices rather than a flaw inherent in GE technology. This discourse can lead to a misrepresentation of the complexities involved in herbicide resistance and its implications for agricultural sustainability. As the debate surrounding superweeds and glyphosate resistance unfolds, it is essential to recognize the urgent need for an integrated approach to weed

management. Currently, species such as *Lolium rigidum* and *Amaranthus palmeri*, which exhibit resistance to twelve and eleven MOAs respectively, are prime examples of the challenges posed by superweeds. Other species, contributing to the growing list of problematic weeds are presented in table 1.



Fig 3. *Lolium rigidum* Fig 4. *Amaranthus palmeri*

Table 1. Major Weed Species Exhibiting Resistance to Multiple Herbicide MOAs

Sl .	Common Name	Scientific Name	Family	Reported resistance (no. of MOAs)
1	Rigid ryegrass	<i>Lolium rigidum</i>	Poaceae	12
2	Palmer amaranth	<i>Amaranthus palmeri</i>	Amaranthaceae	11
3	Barnyard grass	<i>Echinochloa crus-galli</i>	Poaceae	9
4	Goosegrass	<i>Eleusine indica</i>	Poaceae	8
5	Waterhemp	<i>Amaranthus tuberculatus</i>	Amaranthaceae	7
6	Wild oat	<i>Avena fatua</i>	Poaceae	7
7	Horseweed	<i>Conyza canadensis</i>	Asteraceae	6
8	Black-grass	<i>Alopecurus myosuroides</i>	Poaceae	6
9	Green foxtail	<i>Setaria viridis</i>	Poaceae	5
10	Large crabgrass	<i>Digitaria sanguinalis</i>	Poaceae	4

Rethinking Weed Management

Efforts to combat glyphosate-resistant weeds are increasing costs for farmers and decreasing yields, ultimately impacting their profits. As weed resistance grows, farmers are forced to apply more herbicides, including those that are more toxic than glyphosate which has resulted in rise in herbicide use by 25% annually. Moreover, farmers are returning to more

intensive management practices, such as ploughing fields to eradicate resistant weeds, which reduces their reliance on minimum and no-till farming methods. Therefore, to effectively manage the issue of superweeds, a holistic and multifaceted strategy is imperative. Integrated Weed Management (IWM) combines cultural, mechanical, biological, and chemical practices to create a robust defence against weed populations. By diversifying weed management strategies, farmers can reduce reliance on any single herbicide, thereby minimizing the selective pressure that fosters resistance. Strategic tillage practices, including periodic deep ploughing, help disrupt the weed seed bank and destroy perennial weed propagules, while subsequent cultivation prevents seedling establishment. Crop rotation alters agronomic practices and microclimates, limiting the dominance of specific weed species, with pulse crops further suppressing weeds through improved soil cover. Herbicides should be used judiciously and only when weed populations exceed economic threshold levels, following recommended doses to avoid crop injury and environmental harm. Rotating herbicides with different modes of action and using compatible herbicide mixtures enhances broad-spectrum control and reduces the risk of resistance development.

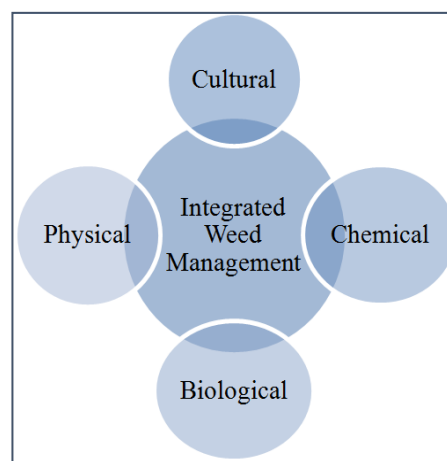


Fig 5. Components of IWM

Furthermore, research must focus on understanding the mechanisms of glyphosate susceptibility and resistance. Investigating dose-response relationships and variations in glyphosate

susceptibility across different populations through methods such as shikimate accumulation analysis will provide valuable insights. These studies can inform more effective management practices tailored to specific weed populations, ultimately leading to improved agricultural sustainability. In conclusion, the rise of glyphosate-resistant superweeds presents a complex challenge that necessitates a comprehensive re-evaluation of current weed management practices. While GR crops have undoubtedly transformed agriculture, their associated risks underscore the need for a more sustainable approach to weed control. By embracing IWM and fostering ongoing research, the agricultural community can develop strategies that not only address the immediate threat of superweeds but also promote long-term ecological balance and agricultural resilience. Only through such concerted efforts can we navigate the intricacies of modern agriculture while safeguarding our environment and food security for future generations.

Summary

The extensive adoption of GR crops has revolutionized weed management by enabling efficient, flexible, and cost-effective weed control, particularly under conservation tillage systems. However, over reliance on glyphosate has led to strong selection pressure on weed populations, accelerating the evolution of GR weeds, commonly termed “superweeds. The scientific basis and global extent of glyphosate resistance, clarifies misconceptions surrounding superweeds, and highlights major multi-herbicide-resistant species threatening crop productivity. It reveals that resistance arises through evolutionary selection rather than herbicide-induced mutation. Therefore, a shift from single-herbicide dependence toward IWM is necessary to ensure long-term agricultural sustainability and agro-ecosystem resilience.

AUTHORS' DETAILS:

Miss. Mayuri J.

Konduskar

*E.X M.Sc. (Agri.) Students
Department of Agricultural
Extension College of Agriculture,
DBSKKV, Dapoli, Ratnagiri,
Maharashtra state*

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VEGETABLE CULTIVATION TECHNOLOGY: FROM HEALTHY SEEDLINGS TO HIGHER RETURNS

ABSTRACT

Vegetables are an indispensable part of the Indian food system, contributing significantly to nutrition, food security, and farm income. They are rich sources of vitamins, minerals, proteins, antioxidants, and dietary fibre, making them essential for a healthy and balanced diet. At the same time, vegetable cultivation offers farmers an opportunity to generate comparatively higher returns from limited land within a short production cycle. However, successful vegetable production is not simply a matter of sowing seeds and applying fertilizers. It requires scientific management at every stage—from nursery preparation and seed treatment to irrigation, crop support, plant protection, harvesting, and post-harvest handling. Modern technologies such as protected and healthy nursery production, drip irrigation, balanced nutrient management, staking and trellising, and integrated pest and disease management can substantially improve productivity and produce quality. Chilli is one of Maharashtra's important commercial vegetable crops and is cultivated under different agro-climatic and seasonal conditions. Adoption of improved cultivation practices can help farmers reduce production risks, conserve resources, improve crop quality, and increase profitability. This article highlights important technologies for efficient and sustainable vegetable production, with special emphasis on nursery management, water management, crop support, harvesting, and chilli cultivation.

INTRODUCTION

India is predominantly an agricultural country, and vegetable crops occupy an important position in its farming economy. With increasing awareness about healthy diets and nutritional security, the demand for quality vegetables continues to grow. Vegetables supply essential vitamins, minerals, fibre, proteins, antioxidants, and other health-promoting compounds required for human well-being. Maharashtra's diverse climate and soil conditions provide favourable opportunities for growing a wide range of vegetables throughout the year. Crops such as tomato, chilli, brinjal, cucumber, bitter gourd, ridge gourd and other vegetables can be cultivated in different seasons with suitable management practices. Vegetable cultivation can be a profitable enterprise because many crops mature within a relatively short period and can provide regular income. Nevertheless, profitability depends greatly on the quality of planting material and the efficiency with which water, nutrients, pests, diseases, and harvesting are managed. The foundation of a successful vegetable crop is a healthy seedling, while the foundation of profitable vegetable farming is scientific management.

1. Healthy Nursery: The First Step Towards a Healthy Crop

The nursery is often called the "birthplace of the crop." A strong, healthy, vigorous, and disease-free seedling has a better chance of establishing rapidly after transplanting and ultimately producing higher yields.

Scientific nursery management also offers an additional opportunity for farmers and rural youth to develop nursery raising as an allied agricultural enterprise.

Selection of Nursery Land

An ideal nursery site should have:

- Loose, fertile and well-drained soil.
- A reliable source of good-quality irrigation water.
- Adequate drainage to prevent waterlogging.
- Good sunlight and ventilation.
- Freedom from perennial weeds such as Cynodon and Cyperus.

Low-lying and waterlogged areas should be avoided because excess moisture encourages root diseases and damping-off.

Land Preparation

Proper preparation of the nursery bed creates a favourable environment for seed germination and root development.

- Plough the land to a depth of about 20–25 cm.
- Carry out two to three harrowings in cross directions to obtain a fine tilth.
- Remove weeds, stones and previous crop residues.
- Incorporate well-decomposed farmyard manure before final bed preparation.
- Ensure proper drainage around the nursery area.

Raised-Bed Preparation

Raised beds are preferred because they improve drainage and aeration around the root zone. Nursery beds of approximately 30 × 10 × 0.15 m may be prepared according to the crop and available space.

Before sowing, suitable soil amendments and recommended fertilizers may be incorporated uniformly into the bed. The use of well-decomposed organic manure and biological inputs can further support healthy seedling development.

2. Seed Treatment: Small Step, Big Protection

High-quality seed is the starting point of a productive crop. Seed treatment protects young seedlings from several seed- and soil-borne pathogens and promotes healthy establishment.

Traditionally recommended fungicides such as

Thiram, Captan or Carbendazim have been used for seed treatment at appropriate label-recommended doses. Where possible, farmers should also adopt biological seed treatment with beneficial microorganisms such as Trichoderma as part of an integrated crop protection programme.

Healthy seed + healthy nursery = stronger crop establishment

Seed treatment should always be carried out using currently approved products and label-recommended doses, as pesticide recommendations and registrations may change over time.

3. Scientific Sowing for Uniform Seedlings

Uniform sowing is essential for obtaining seedlings of similar age and vigour.

During summer, nursery beds should be irrigated before sowing and allowed to reach suitable moisture conditions. Seeds may then be sown in rows approximately 8–10 cm apart and at a depth of 1–1.5 cm, depending on seed size and crop.

After sowing:

- Cover the seeds lightly with fine soil.
- Irrigate gently using a watering can or fine sprinkler.
- Avoid heavy irrigation that may displace seeds or cause soil crusting.
- Maintain adequate moisture until germination.
- Provide sufficient ventilation and sunlight.

Uniform emergence makes subsequent nursery management and transplanting easier.

4. Protecting the Young Seedlings

The seedling stage is one of the most vulnerable phases of vegetable production. Damping-off, thrips and other pests can severely affect nursery establishment if preventive measures are neglected.

Integrated Pest and Disease Management

Instead of depending solely on chemical sprays, farmers should adopt an Integrated Pest and Disease Management (IPDM) approach involving:

- Use of healthy and treated seed.
- Clean nursery beds and tools.
- Proper drainage and irrigation management.
- Removal of infected seedlings.
- Regular monitoring for insects and diseases.

- Use of biological control agents where appropriate.
- Application of registered pesticides only when necessary and according to label recommendations.

Damping-off can be particularly serious under excessive moisture and poor drainage. Therefore, “more water” does not mean “better seedlings.”

5. Nutrient Management in the Nursery

Seedlings require balanced nutrition for strong roots, stems and leaves. Excessive fertilizer application, however, can damage delicate seedlings. At different growth stages, nutrients should be supplied according to crop requirement, soil fertility and recommended package of practices. Nitrogenous fertilizers such as urea should be applied carefully and away from direct contact with seedlings. Organic manures, compost and suitable biofertilizers can be integrated into the nutrient management programme to improve soil health.

6. Transplanting: Giving Seedlings a New Home

Vegetable seedlings are generally ready for transplanting when they have developed adequate root and shoot growth, commonly around 4–6 weeks, depending on the crop and growing conditions.

Before uprooting:

- Withhold irrigation for a few days to harden the seedlings.
- Give light irrigation before removal if the soil is too dry.
- Uproot seedlings carefully to minimize root damage.
- Select only healthy, vigorous and disease-free seedlings.
- Transplant preferably during cooler hours of the day.

Before transplanting, biological root treatment with beneficial organisms such as *Trichoderma* may be used as recommended.

Careful transplanting reduces transplant shock and promotes rapid establishment.

7. Water Management: Every Drop Counts

Water is one of the most critical resources in vegetable production. Both excess water and inadequate moisture can reduce yield and quality.

Vegetable crops have shallow and active root systems, making them particularly sensitive to fluctuations in soil moisture.

Smart Irrigation Practices

- Avoid waterlogging by providing proper drainage.
- Prevent moisture stress during critical growth stages.
- Schedule irrigation according to soil type, weather conditions and crop growth stage.
- Avoid unnecessary irrigation.
- Prefer drip irrigation wherever feasible.
- Use mulching to reduce evaporation and maintain soil moisture.

Indicative irrigation intervals may vary with crop, soil and weather conditions:

Season General Irrigation Guidance

Rainy season: As required, depending on rainfall

Winter: Approximately every 10–15 days, depending on soil moisture

Summer: Approximately every 5–6 days, depending on crop and soil

These intervals should be treated as general guidance rather than fixed rules. Actual irrigation should be based on soil moisture and crop requirement.

Drip Irrigation: More Crop with Less Water

Drip irrigation delivers water directly to the crop root zone, reducing losses through evaporation and unnecessary wetting of the soil surface. Fertilizers can also be supplied through fertigation when appropriate. For water-scarce regions, drip irrigation combined with mulching can be a powerful tool for improving water-use efficiency.

8. Staking and Training: Supporting the Crop for Better Production

Some vegetable crops benefit greatly from physical support. Tomato, chilli and brinjal can be trained or supported according to crop type and local production practices.

- Benefits of Staking
- Keeps plants upright.
- Improves exposure to sunlight and air circulation.
- Keeps fruits away from direct soil contact.
- Reduces mechanical damage.

- Can reduce the risk of certain soil-borne diseases.
- Improves fruit appearance and market quality.
- Makes harvesting and crop management easier.

Proper training should begin at the appropriate crop growth stage rather than after plants become excessively large.

9. Trellising Vine Crops: Turning Space into Production

Vine crops such as ridge gourd, bitter melon and cucumber can be trained on bower or trellis systems. Bamboo poles, wires, ropes or other suitable support structures can be used. The vines should be guided regularly so that they receive adequate sunlight and ventilation.

A well-designed trellis can:

- Improve utilization of vertical space.
- Keep fruits clean and attractive.
- Improve air circulation.
- Facilitate harvesting.
- Reduce fruit contact with wet soil.
- Potentially improve yield and marketable quality.

For small and marginal farmers, efficient use of vertical space can be particularly valuable.

10. Chilli Cultivation: A High-Value Vegetable Enterprise

Chilli is one of Maharashtra's important commercial vegetable and spice crops. It can be grown under different seasons and production systems depending on the region, variety and market requirement.

Successful chilli cultivation begins with the selection of a suitable, high-quality variety and healthy planting material.

Important components of improved chilli production include:

- Selection of suitable varieties according to local climate and market demand.
- Production of healthy, disease-free seedlings.
- Proper spacing and field preparation.
- Balanced application of organic and inorganic nutrients based on soil-test results.

- Efficient irrigation, preferably through drip systems where feasible.
- Regular monitoring of thrips, mites, aphids, fruit borers and other important pests.
- Integrated management of viral and fungal diseases.
- Removal of severely affected plants where recommended.
- Timely harvesting according to market requirements.

Because chilli is sensitive to several pest and disease problems, regular field scouting is more effective than waiting until damage becomes severe.

11. Harvesting: The Right Crop at the Right Time

Harvesting is not merely the final operation—it directly influences price, quality and shelf life.

Vegetables should generally be harvested at the stage appropriate for their intended market. Tender vegetables are often preferred for fresh consumption, while chilli may be harvested at different stages depending on whether green or mature/dry produce is required.

Good Harvesting Practices

- Harvest during the cooler hours of the morning or evening.
- Use clean and suitable harvesting tools.
- Avoid unnecessary pulling, twisting or dropping of produce.
- Handle vegetables gently to minimize bruising and mechanical injury.
- Harvest at the correct maturity stage.
- Avoid leaving over-mature produce on plants for longer than necessary when frequent harvesting is required.

Timely harvesting means better quality, better appearance and often better market value.

12. Post-Harvest Management: Protecting the Farmer's Effort

A crop can be produced successfully and still lose value because of poor post-harvest handling. Therefore, quality management must continue even after harvesting.

Immediately after harvest:

- Remove damaged, diseased and rotten vegetables.
- Grade produce according to size, colour, maturity and quality.
- Handle vegetables carefully to prevent bruising.
- Keep harvested produce away from direct sunlight for as long as practical.
- Use clean containers and packaging materials.
- Wash produce only when appropriate for the crop and marketing system, using clean water.

Follow proper storage and transportation practices.

Reducing post-harvest losses is effectively equivalent to producing more marketable vegetables without increasing the cultivated area.

The Future of Vegetable Farming

The future of vegetable cultivation lies in combining traditional farming knowledge with modern scientific technology. Precision irrigation, soil testing, fertigation, improved varieties, protected nursery production, biological pest management, mulching, digital weather information and improved post-harvest practices can help farmers produce more with fewer resources.

For sustainable vegetable production, the focus should shift from simply asking:

“How much can we produce?” to

“How much quality produce can we produce profitably, sustainably and with efficient use of every resource?”

CONCLUSION

Vegetable cultivation has tremendous potential to improve farm income, nutrition and rural employment. However, higher productivity cannot be achieved through a single technology. It is the result of a series of well-timed decisions—from selecting quality seed and raising healthy seedlings to managing water and nutrients, protecting the crop, supporting plants, harvesting at the right stage and reducing post-harvest losses. For farmers in Maharashtra and other vegetable-growing regions, scientific nursery management, efficient irrigation, balanced nutrition, integrated pest and disease management, proper staking and trellising, and improved harvesting practices can form the backbone of profitable and sustainable vegetable production. A healthy seedling builds a strong crop; a well-managed crop builds a profitable farm.

AUTHORS' DETAILS:

Anushka Karn¹,

Aditi Vats²,

Karuna Irungbam^{3*}

¹ B.Tech. Biotechnology Student

² Research Trainee

^{3*} Senior Scientist and
Corresponding Author

Division of Biochemistry,
ICAR-Indian Veterinary
Research Institute, Izatnagar,
Bareilly – 243 122, Uttar
Pradesh, India

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SODIUM AZIDE- The Tiny Preservative with Big Safety Concern

Sodium Azide:

Imagine a chemical that is so powerful that only a small amount is required to preserve reagents and solutions in the laboratory and that same chemical can become dangerous if handled the wrong way. This is **Sodium azide**.

Most people have never heard of the name 'sodium azide' but it plays a crucial role in science around the world. Like many other powerful chemicals, sodium azide also comes with an important warning. The same properties that make it useful also makes it extremely dangerous if handled incorrectly.

At first sight, sodium azide (NaN_3) doesn't look unusual at all. It is a white, crystalline powder with no noticeable smell just like table salt. Despite its ordinary appearance, sodium azide comes with a remarkable property. Scientists discovered that in tiny amounts, sodium azide could effectively prevent microbial growth in laboratory reagents.

When we talk about the history of sodium azide and the broader azide family, two pioneering scientists stand out: **Johann Peter Griess** and **Theodor Curtius** [1]. In 1858, Peter Griess discovered diazotization process which is a process that converts primary aromatic amines to diazonium salts. Later, he also synthesized the first organic azide known as Phenyl azide in 1864.

In 1890, Theodor Curtius synthesized hydrazoic acid (HN_3) which is the inorganic parent of all azide compounds[1].

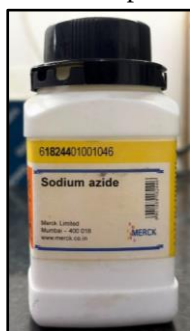


Fig 1: Sodium Azide

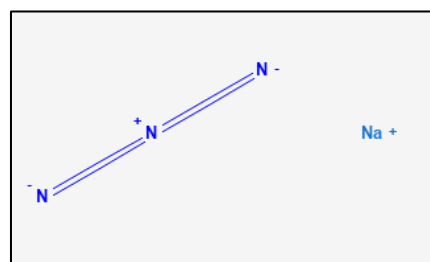


Fig2: Structure of sodium azide (NaN_3). Image source: PubChem
<https://pubchem.ncbi.nlm.nih.gov/image/imgsrv.fcgi?cid=33557&t=l>

Where Do We Find It?

Despite being unfamiliar to most people, sodium azide is found in more places than many people realise:

- **Research laboratories**, where it is added to biological samples and buffers to prevent microbial growth.
- **Diagnostic kits and antibody solutions**
- **Hospitals and clinics**
- In **Agriculture** as pest control[2]

Apart from these uses, sodium azide has been used in **automobile airbags**. For years, sodium azide acted as a key ingredient in airbags. During a car crash, sodium azide undergoes a rapid reaction which releases a large volume of nitrogen gas causing the airbags to inflate almost instantly[3]. Because sodium azide was consumed during the chemical reaction, the people occupying the vehicle were not exposed to sodium azide itself.

In newer generation cars, sodium azide has largely been replaced by other compounds that are considered safer to handle and dispose of.

Applications	Typical CONCENTRATION
Buffers and samples	0.02-0.1% (w/v)
Laboratory reagents	0.02-0.05% (w/v)
Antibody solutions	0.02% (w/v)
Airbags	100-200g

Table1: Typical amount of sodium azide used in in different applications[4,5]

➤ Uses of Sodium Azide in laboratory

The reason is very simple: it is cheap and it works well. One constant but invisible challenge that laboratories have to deal with is microbial contamination. Bacteria and fungi are present almost everywhere and they can grow in reagents and samples due to which an experiment which might have taken weeks to complete can get ruined.

Think of sodium azide as the laboratory equivalent of keeping food in the refrigerator. Refrigerators slow down the growth of microbes and thus increasing shelf life of food. Sodium azide works in similar manner in the laboratory, but instead of cooling them like a refrigerator it prevents growth of microbes at room temperature.

In laboratories, Sodium azide is used in tiny concentrations of just 0.1-2.0% [4], yet it is highly effective. Since it works without requiring special conditions or adding significant cost, it has become trusted preservative in laboratories even though newer and safer are available.

➤ The Hidden Risks

Sodium azide is commonly used as preservative across laboratories but then why do laboratories have to

handle it with special care?

This is because of its toxicity. While sodium azide effectively prevents the growth of microbes but it does not differentiate between microbial cells from other living cells. Once it gets inside the human body, sodium azide interferes with cellular respiration which is the process through which the cells produce energy, which is why even small amounts of sodium azide can be dangerous. Organs like The heart and brain, which rely heavily on oxygen, suffers the most[6].

Accidental exposure can occur through many ways such as inhalation, ingestion, skin or eye contact and may cause symptoms such as headaches, nausea, dizziness, vomiting, breathing problems and a sudden drop in blood pressure (hypotension). Hypotension is considered as the characteristic symptom of sodium azide poisoning where the time duration between exposure and detection of hypotension can predict if the affected person is going to survive or not[7]. Doses equal or more than 700 mg (10 mg/kg) is considered fatal. Whereas in the range of 0.3 to 150 mg (0.004 to 2 mg/kg), it is considered non-fatal[7].

In this case, safe disposal becomes just as important as safe handling. Sodium azide should never be poured down a sink as not only it is harmful to aquatic animals[6], it can also react in many unexpected ways once it enters plumbing. If it comes into contact with acid, it can release **hydrazoic acid** which is a highly toxic gas. If it reacts with copper or lead pipes, it may produce **metal azides** which are highly unstable and under certain conditions, becomes explosive. This is why just “pouring down the drain” is the worst way to dispose of it after use.

No specific cure exists for sodium azide poisoning. So, the best thing for people exposed to sodium azide is to seek medical help as soon as possible[8]. Fortunately, cases of Sodium azide poisoning are uncommon[9]. Strict laboratory protocols, proper storage and careful disposal reduce the risk of accidental exposure.

➤ How To Stay Safe

Now that we understand the risks of Sodium Azide, it is equally important to understand how to reduce these risks. Because when handled carefully, Sodium azide can be a valuable laboratory reagent. Standard precautions while working with Sodium azide include

- Wear appropriate PPE: gloves, goggles, and a lab coat
- Work in a well-ventilated area and keep sodium azide away from heat sources.
- Avoid using metal spatula or spoon while weighing or transferring sodium azide powder
- Always close the container properly when not in use.
- Bottles containing pure powders or solutions of sodium azide at 5% or greater must be opened and handled only in a chemical hood[6].
- Never pour it down a sink or drain
- Follow proper chemical waste procedures when disposing of it.
- Label and storing it in cool, dry place and dark location, away from acids and reactive metals

➤ Can We Replace It?

With all these precautions surrounding sodium azide, it is a natural question that comes to our mind: why don't we simply replace it with something safer? In many cases, we can do it but there are several factors that makes the process complicated.

Safer alternatives such as **ProClin™** (an isothiazolinone-based preservative) and **2-Chloroacetamide** are available[10]. Some eco-friendly preservatives commonly used are **benzyl alcohol**, **salicylic acid**, **sorbic acid**, **gluconolactone**, and **sodium benzoate**. These preservatives are considered safer for both the environment and consumers and offers broad-spectrum protection against microbial contamination in water-based products[4]. In many cases, maintaining sterile working conditions or storing reagents and samples at low temperatures is enough to keep microbial contamination in check.

One thing to note is that no single preservative works for every situation. Each one comes with its own pros and cons in cost or effectiveness or, in safety. Which is one of the reasons why sodium azide, despite its risks, still hasn't disappeared from laboratories.

➤ Conclusion

Sodium azide will probably never make it to science headlines but it has become a permanent member of laboratories around the world. Its anti-microbial

property has made it an important tool for researchers despite the careful handling it requires because of the risks it poses. Reminding us that no chemical is simply “good” or “bad”. The same properties that make one chemical useful can also make it harmful in another. What makes a difference is how well those properties are understood and managed.

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AUTHORS' DETAILS:

Sharad¹

Pawan Kumar²

*Punjab Agricultural
University, Ludhiana
(Punjab)*

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AN INTEGRATED APPROACH TO MANAGING INSECT PESTS OF BRINJAL

Abstract

Brinjal (*Solanum melongena* L.) is a major vegetable crop of India, occupying about 6.81 lakh hectares with an annual production of around 128.10 lakh tonnes. Despite this scale, the crop suffers heavy losses from a complex of insect pests, most notably the brinjal shoot and fruit borer (*Leucinodes orbonalis*), which alone can cause yield losses of up to 90% and is considered one of the most destructive constraints to profitable cultivation. Others major pest include hadda beetle (*Henosepilachna vigintioctopunctata*), whitefly (*Bemisia tabaci*) and spider mite (*Tetranychus urticae*). Left unmanaged, such infestations directly reduce both marketable yield and fruit quality, cutting into grower income. A well-planned strategy combining cultural practices, mechanical intervention, and judicious chemical use, an integrated pest management (IPM) programme offers an effective, economically viable, and environmentally sound means of keeping these losses in check while sustaining productivity.

Keywords-Brinjal, IPM, Insect pest, yield loss, Shoot and fruit borer, yield loss

Introduction

Brinjal (*Solanum melongena*), commonly known as eggplant or aubergine, is among the most economically important vegetable crops grown across the tropics and subtropics. In India, brinjal was cultivated on about 6.81 lakh hectares (681 thousand ha) with a production of 128.10 lakh tonnes (12.81 million tonnes) in 2023-24, a marginal rise in area over the previous year, with West Bengal, Odisha, Gujarat, Madhya Pradesh and Bihar as the leading producing states. India's overall vegetable output rose further by about 5.11 percent in 2024-25, with brinjal among the crops contributing to this growth, and the country remains the world's second-largest brinjal producer after China. Beyond its scale, brinjal holds major economic significance for smallholders, supporting well over a million small family farms with year-round income and food security, making it a key vehicle for rural poverty reduction.

This economic importance is persistently undermined by insect pests. As many as 26 insect species have been recorded attacking brinjal, with the shoot and fruit borer, whitefly, epilachna beetle and mites being the most damaging. Combined infestation by sucking pests and borers can cause yield losses of 70 to 92 percent, while the shoot and fruit borer alone has been reported to destroy up to 86-90 percent of the crop in severe cases, driving farmers toward intensive, often indiscriminate insecticide use. Given this scale of loss and the risks of pesticide overuse resistance, resurgence, residues, and rising costs, Integrated Pest Management (IPM), built on regular monitoring, correct pest identification, and threshold-based intervention, is essential for sustainable brinjal cultivation.



Damage symptom of brinjal fruit & shoot borer on plant



Hadda beetle on a brinjal leaf



Fruit damage by brinjal fruit & shoot borer



1. Brinjal Shoot and Fruit Borer (*Leucinodes orbonalis*)

Of all the insects that attack brinjal, the shoot and fruit borer causes the most damage and is found in virtually every brinjal growing region of the country. A single female moth can lay anywhere between 80 and 120 eggs, which are pale, creamy white, and usually placed one at a time or in tiny clusters of two to four. The female tucks them away on the undersides of leaves, along stems, near flower buds, or right at the calyx of the fruit. Once the larva has fed enough, it pupates inside a tough silken cocoon, often hidden among fallen leaves and other debris on the ground.

Symptoms of Damage

Freshly hatched caterpillars tunnel straight into the tender shoots and leaf stalks, feeding from within. The affected shoots soon wilt and droop, giving the plant a noticeably sagging appearance. Once fruiting begins, the larvae shift their attention to young fruits, entering through the calyx and continuing to feed inside. By the time the larvae are fully grown, the damage shows up as visible exit holes on the fruit surface. Leftover crop debris and stalks after harvest act as a hiding place for the pest, letting it carry over and infest the next planting.

Management

Economic Threshold Level (ETL): Chemical intervention is warranted only when infestation crosses the threshold, generally taken as 5 percent shoot damage or 1-2 larvae per plant at the vegetative stage, or around 5 percent fruit infestation at fruiting. Below this level, monitoring and non-chemical measures should continue without spraying.

Cultural control

- Avoid raising a ratoon crop of brinjal, since it allows the pest to carry over to the next season.
- Follow crop rotation with a non-solanaceous crop to break the pest's continuity in the field.
- Transplant early (March–April) or late (July) where feasible, since timing influences the extent of borer buildup.

Mechanical/physical control

- Inspect the field regularly and clip off wilted shoots and infested fruits at weekly intervals, destroying the larvae inside rather than simply discarding the plant part in the field.
- Collect and destroy dropped or unmarketable infested fruits to prevent larvae from completing their life cycle.

Monitoring and mass trapping with pheromones

- Install *Leucinodes orbonalis* sex pheromone traps at about 5 traps per acre for monitoring adult moth activity from the time of transplanting.
- Where infestation pressure is high, increase density to 8–10 traps per acre for mass trapping, which disrupts mating and reduces the next larval generation.
- Replace lures every 3–4 weeks, and use trap catches as a guide for deciding when other interventions are needed rather than relying on a fixed spray calendar.

Botanical/neem-based measures

- Spray neem seed kernel extract (5%) or azadirachtin-based formulations (0.03-1%) at 10-15 day intervals as an early-stage and rotational measure; these act as antifeedants and growth disruptors with low toxicity to natural enemies.

Chemical control (only above ETL, used judiciously)

When the pest population exceeds the ETL and non-chemical measures are insufficient, one of the following may be applied in 100-125 litres of water per acre, rotating between different chemical groups across the season to delay resistance development and never repeating the same mode of action in consecutive sprays:

- Chlorantraniliprole 18.5 SC at 80 ml per acre
- Emamectin benzoate 5 SG at 80 g per acre
- Fenvalerate 20 EC at 100 ml per acre
- Cypermethrin 10 EC at 200 ml per acre
- Deltamethrin 2.8 EC at 160 ml per acre

A pre-harvest interval must be respected: wait at least 3 days after spraying Proclaim and 7 days after spraying Coragen before picking the fruits.

2. Hadda Beetle (*Henosepilachna vigintioctopunctata*)

The hadda beetle becomes a serious concern for brinjal growers between May and September. Its grubs are yellowish and easy to recognise by the rows of branched, spine-like projections running along their bodies. These grubs need only 10 to 35 days to reach full size. The pupae are darker and are usually found clinging to leaves, stems, or lying close to the base of the plant. From egg to adult, the entire life cycle wraps up in about 25 to 50 days.

Symptoms of Damage

Both the grubs and the adult beetles feed by scraping off the green chlorophyll layer from the leaf surface, leaving the veins behind untouched. This creates a distinctive lace like, skeletonised pattern on the foliage. When the infestation is heavy, even the calyx covering the fruit does not escape their feeding. Over time, the affected leaf tissue dries up and drops off, leaving visible holes and reducing the plant's ability to photosynthesise effectively.

Management

- **ETL:** Act when egg clusters/grubs are seen on >10% plants or defoliation becomes noticeable (before it reaches damaging levels).
- **Cultural:** Remove and destroy solanaceous weed hosts (*Solanum nigrum*, *S.*

xanthocarpum, etc.) near the field that carry the beetle between seasons.

- **Mechanical:** Look out for egg clusters and leaves showing the skeletonised feeding pattern, along with any grubs and beetles present, and remove and destroy them. On smaller plots, adults can be physically removed using a hand net, particularly when infestation is just starting.
- **Biological control:** Conserve predators like *Rhinocoris fuscipes*, release the parasitoid *Pediobius foveolatus* where available, which attacks the grub stage effectively.
- **Botanical:** Spray neem oil or neem seed kernel extract (5%), which disrupts feeding and reproduction; apply neem cake (300 kg/ha) into soil before transplanting as a preventive measure.
- **Chemical (only above ETL):** Use one, rotating groups carbaryl 50% WP (0.1%), quinalphos 25% EC (0.05%), or thiamethoxam 25% WG (0.1%) never the same group in consecutive sprays.

Resistance management: Limit each active ingredient to 1-2 sprays/season, alternate modes of action with biological/botanical rounds in between.

3. Whitefly (*Bemisia tabaci*)

Whitefly is not fussy about its host and readily feeds on a wide variety of cultivated as well as wild plants. Both the young nymphs and the winged adults pierce the plant tissue to draw out sap, gradually sapping the plant's vigour. As they feed, they excrete a sugary substance called honeydew, which in turn encourages the growth of sooty mould on the leaf surface. This coating interferes with the plant's ability to photosynthesise, and over time, growth slows down and yields drop noticeably.

Management

The economic threshold for whitefly in brinjal is set at 9 adults per leaf. Once populations reach this level, any of the following options can be used:

- Neem extract, applied at 1200 ml per acre, or
- Juice extracted from maize, sorghum, or bajra, applied at 1500 ml per acre, mixed in 100–125 litres of water per acre

A follow-up spray after 7 days may be needed if the pest persists. Where the infestation is particularly severe, Diafenthiuron 50 WP can be used at 200 g per acre in 100-125 litres of water.

Preparing of Neem Extract

Take 4.0 kg of the terminal portions of neem shoots, including the leaves, tender twigs, and fruits, and boil them in 10 litres of water for 30 minutes. Strain the mixture through a piece of muslin cloth and use the resulting filtrate for spraying at the recommended dose.

4. Spider Mites (*Tetranychus urticae*)

Spider mites tend to flare up during May and June, especially when the weather turns hot and dry. The first indication of their presence is a scattering of tiny yellowish white specks on the leaves. As the mite population builds up, the leaves begin to show a scorched appearance and eventually drop off the plant. Leaves under mite attack also tend to collect a good deal of dust, which further cuts down on the plant's photosynthetic efficiency.

Management

- Refrain from growing a ratoon crop of brinjal.
- Do not delay or skip irrigation during May and June, since dry conditions allow mite populations to multiply rapidly.
- Spray Propargite 57 EC at 300 ml per acre in 150 litres of water.
- Observe a one-day waiting period after spraying Omite before the produce is harvested.

Conclusion

At the end of the day, keeping brinjal free of major pest damage comes down to consistent field monitoring, catching problems while they are still small, and acting only when action is genuinely needed. A combination of cultural practices, mechanical removal, and carefully chosen chemical treatments not only brings down crop losses but also cuts back on unnecessary pesticide use. The end result is better fruit quality, higher marketable yield, and a brinjal enterprise that is both more profitable and more sustainable for the grower.

AUTHORS' DETAILS:

Manvir Singh Sidhu

*Department of Floriculture &
Landscaping, Punjab Agricultural
University, Ludhiana, Punjab-
141004, India*

Rishu Sharma

*Department of Floriculture &
Landscaping, Punjab Agricultural
University, Ludhiana, Punjab-
141004, India*

Shagun Sharma

*Department of Floriculture &
Landscaping, Punjab Agricultural
University, Ludhiana, Punjab-
141004, India*

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Carbon Sequestration Potential of Turfgrass Systems for Climate Change Mitigation

Abstract

As the climate crisis intensifies, finding effective natural methods for capturing and storing atmospheric carbon dioxide (CO₂) is more urgent than ever. Turfgrasses, commonly found in lawns, parks, sports fields, and urban green spaces, offer an often-overlooked solution. Through the process of photosynthesis, turfgrasses absorb CO₂ from the atmosphere and convert it into carbohydrates, which are stored in their shoots, roots, and surrounding soil. This process increases soil organic carbon (SOC), promoting healthier soils and long-term carbon storage. Turfgrass systems are accessible, scalable, and can be strategically deployed in urban and suburban areas to help mitigate rising CO₂ emissions. In a world facing escalating climate challenges, harnessing the power of turfgrasses offers a practical and sustainable way to combat climate change.

Keywords: Climate; CO₂; Soil organic carbon

Introduction

Climate change has become a public concern in recent years. While many factors may contribute to climate change, greenhouse gases (GHGs) including carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) have attracted much attention. The atmospheric concentrations of these GHGs have steadily risen during the last century, among which CO₂ has been considered a major factor for global warming and climate change in the same period. In the battle against rising atmospheric CO₂ concentrations, carbon sequestration emerges as a powerful method, offering a natural mechanism to mitigate climate change. Carbon sequestration refers to the process of capturing and storing carbon in organic form within soil organic matter. Experts suggest that soil carbon sequestration can reduce the buildup of CO₂ in the atmosphere while enhancing soil, air, and water quality, as well as benefiting the agricultural economy. Among the various plants contributing to this crucial process, turfgrasses play an increasingly significant role due to their widespread presence in urban landscapes and their capacity to act as carbon sinks. With their extensive root systems and dense foliage, turfgrasses can effectively sequester carbon through photosynthesis, storing it in their biomass and the surrounding soil. These grasses have the potential to absorb more CO₂ than they release, making them valuable assets in efforts to reduce greenhouse gas concentrations. Despite the potential, data on turfgrass cultivation in India remains limited.

Estimates from golf associations, sports experts, and the Association of Indian Nurserymen indicate that the turfgrass industry covers over 30,000 acres, with approximately 4,500 acres dedicated to turfgrass cultivation and sod production. This untapped potential offers a promising avenue for enhancing carbon sequestration in urban and suburban areas.

As cities expand and green spaces become more essential for environmental balance, harnessing the carbon-sequestering power of turfgrasses provides a practical, scalable, and sustainable strategy for addressing the climate crisis. By understanding and optimizing the role of turfgrasses, we can transform everyday green spaces into effective carbon sinks, contributing to a healthier planet for future generations.

Mechanisms by Which Turfgrasses Contribute to Carbon Sequestration

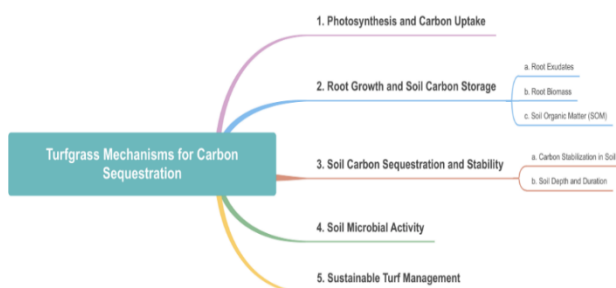


Figure 1 Different mechanism for carbon sequestration

The first mechanism is photosynthesis and carbon uptake, where turfgrass plants capture atmospheric CO₂ and convert it into organic carbon compounds through photosynthesis. Secondly, root growth and soil carbon storage highlights how root exudates, root biomass, and soil organic matter (SOM) contribute to the accumulation of carbon in the soil, enhancing soil quality and carbon retention. The third mechanism, soil carbon sequestration and

stability, focuses on the stabilization of carbon within the soil structure and the depth and duration of carbon storage, ensuring long-term sequestration. Additionally, soil microbial activity plays a vital role in breaking down organic matter and facilitating carbon incorporation into the soil matrix. Finally, sustainable turf management practices are essential to optimize these processes, ensuring that turfgrass systems remain effective in sequestering carbon while maintaining environmental sustainability.

Factors Influencing Carbon Sequestration in Turfgrass Systems

Several factors affect the ability of turfgrasses to sequester carbon:

- Species Selection:** Different turfgrass species vary in root depth, growth rate, and biomass production, all of which influence their carbon sequestration capacity. Deep-rooted species like Bermuda grass can transfer carbon to deeper soil layers, enhancing long-term sequestration. Zoysia grass species with high shoot density are likely better at assimilating atmospheric CO₂ (increased carbon inputs into the turfgrass soil system). Comparison studied has been presented here under;

Species	Sequestered C (Mg ha ⁻¹ ·yr ⁻¹)	
Bermuda grass (<i>Cynodon dactylon</i> (L.) Pers. × <i>C. transvaalensis</i> Burt & Davy)	2.09 ± 0.11	Hamido et al., 2016
Centipede grass (<i>Erecholmoa ophroides</i>)	4.23 ± 0.14	
Zoysia grass (<i>Zoysia</i> spp.)	5.54 ± 0.21	

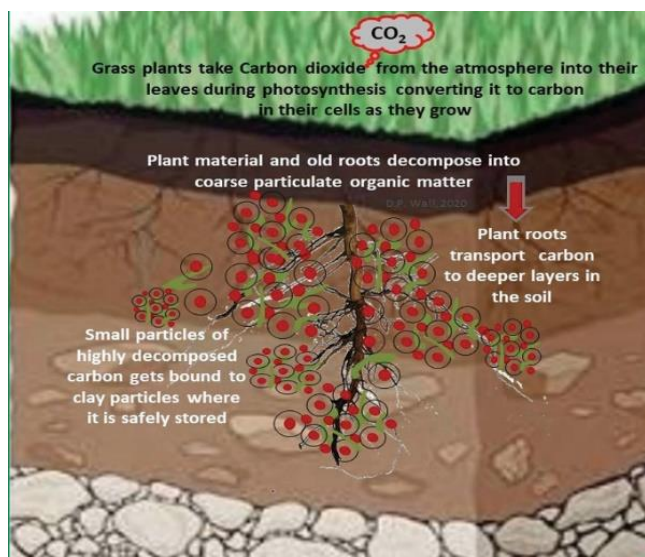


Figure 2 Carbon sequestration by turfgrasses and transport to deeper layers

- **Management Practices:** Proper management practices are crucial for minimizing biotic and abiotic stresses in turfgrass. When turfgrass is under stress, respiration exceeds photosynthesis, resulting in CO₂ release into the atmosphere. Irrigation, fertilization, and mowing practices can positively or negatively affect the ability of turfgrass systems to assimilate and store carbon.
- **Soil Type and Health:** Healthy soils play a crucial role in carbon sequestration, with different soil types offering unique benefits. Loamy soils promote balanced root growth and effective carbon storage, while clay soils retain more organic matter, supporting long-term carbon storage. In contrast, sandy soils drain well but lose carbon more rapidly. Enriching soils with organic matter and fostering active microbial activity enhance their capacity for stable carbon sequestration. Practices like aeration, reducing compaction, and adding organic amendments improve soil structure and nutrient availability, further supporting this vital ecological process.
- **Climate Conditions:** Warmer temperatures and longer growing seasons can promote greater carbon input through photosynthesis. Higher organic carbon contributions through turfgrass

cutting as a result of high aboveground yield and higher organic C content in warm season turfgrasses when compared with cool season grasses, as the maximum temperatures and high CO₂ assimilation rate during summer and early autumn for warm season grasses.

Sustainable Turfgrass Management Strategies to enhance the carbon sequestration

To maximize the carbon sequestration potential of turfgrasses, sustainable practices should be adopted:

1. **Reduce Fertilizer Use:** Use organic fertilizers (e.g., compost or biochar) or slow-release nitrogen fertilizers (Polymer-Coated Urea or Sulphur Coated Urea) to minimize emissions.
2. **Efficient Irrigation:** Water conservation practices (e.g., drought-tolerant grass species, smart irrigation) reduce energy usage related to water distribution, indirectly cutting CO₂ emissions.
3. **Soil Aeration and Compaction Control:** Regular aeration promotes root growth and increases soil organic carbon. Reducing soil compaction enhances oxygen levels and root health, supporting sequestration.
4. **Incorporate Native Grass Species:** Native grasses typically require less maintenance and are well-adapted to local conditions.

Conclusion

In conclusion, Turfgrasses, beyond their aesthetic appeal, serve as effective carbon sinks, capturing and storing atmospheric carbon through their extensive root systems and soil interactions. With proper management such as optimized fertilization, irrigation, and reduced fossil-fuel inputs turfgrasses can significantly contribute to climate change mitigation while providing ecosystem services like erosion control,

microclimate regulation, and urban cooling. To maximize their potential, a shift toward sustainable practices and species selection with high carbon-storing capacity is essential. Turfgrasses are not just ornamental but critical assets in global carbon neutrality efforts, offering an eco-friendly approach to creating resilient urban ecosystems and combating climate change.

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Figure 2 [2020 - Protecting soil carbon stocks and enhancing Carbon Sequestration - Teagasc | Agriculture and Food Development Authority](#)

AUTHORS' DETAILS:

**Mr. D.
LOKESHWARAN**

*Ph.D. Research Scholar,
Department of agricultural
Extension,
Faculty of agriculture,
Annamalai University,
Chidambaram,
Tamilnadu -608002*

ARTICLE ID: 06

ADVANCED TECHNOLOGIES FOR SUSTAINABLE FOOD PRODUCTION: INNOVATIONS AND FUTURE PERSPECTIVES

ABSTRACT

The growing global population, along with climate change and the depletion of our natural resources, poses serious challenges to food production. Traditional farming methods, which often depend on manual labour, excessive water use, and chemical inputs, can lead to environmental harm and resource depletion. To ensure food security while keeping agriculture's ecological impact in check, sustainable food production is crucial. That's where robotics comes in combined with Artificial Intelligence (AI), the Internet of Things (IoT), and machine learning, it's transforming the way we produce food by boosting efficiency, cutting down on waste, and optimizing resource use. This study delves into how robotics plays a role in different areas of food production, such as precision agriculture, smart irrigation, robotic harvesting, livestock farming, fisheries, and food processing. In precision agriculture, robots equipped with sensors and AI technology help optimize planting, monitoring, and crop management. Smart irrigation systems use robotic sensors to deliver water more efficiently, tackling the challenges of water scarcity. Automated harvesting technologies enhance efficiency and reduce food loss by accurately identifying and picking ripe produce. In livestock farming, robotic systems improve feeding, health monitoring, and milking, promoting ethical and resource-efficient animal agriculture. Robotics in fisheries and aquaculture aim to reduce overfishing and streamline fish farming operations, while robotic food processing and supply chain management work to minimize food waste and enhance logistics. By bringing robotics into the world of food production, farmers and food producers can boost their yields, lessen their environmental footprint, and meet the increasing global food demand in a sustainable way. That said, there are hurdles to overcome, like the hefty initial costs, the need for technical know-how, and various ethical concerns that must be tackled for these technologies to be widely embraced. In conclusion, this paper argues that robotics will be crucial in building a food production system that is not only more sustainable but also resilient to climate change and more efficient for the future

Introduction

The Need for Sustainable Food Production

The global population is projected to hit 9.7 billion by 2050, which means we're going to need a lot more food. Unfortunately, traditional farming methods are becoming less viable because they rely heavily on manual labor, waste a lot of water, and depend on chemical fertilizers and pesticides. These practices are leading to soil degradation, loss of biodiversity, deforestation, and increased greenhouse gas emissions, all of which put our long-term food security and the health of our planet at risk. On top of that, climate change is throwing a wrench into weather patterns, leading to droughts and floods that reduce crop yields, making it even harder to feed a growing population.

To tackle food security without further damaging the environment, we need to embrace sustainable and resource-efficient farming practices. The integration of robotics, AI, IoT, and machine learning presents exciting opportunities by automating labor-intensive tasks, optimizing resource use, and cutting down on waste. These technological advancements can boost productivity, enhance precision, and improve efficiency in food production, all while significantly reducing our ecological footprint.

The Role of Robotics in Agriculture and Food Systems

Robotics is already making waves in different stages of food production. From planting and monitoring to harvesting and packaging, autonomous robots, drones, and AI-driven systems are boosting efficiency and sustainability. Precision agriculture uses drones and self-driving tractors to assess soil conditions and apply fertilizers, water, and pesticides precisely where they're needed, cutting down on waste and protecting the environment. Smart irrigation systems make the most of water by using robotic sensors to check soil moisture and adjust watering schedules as needed. Automated harvesting robots leverage AI and computer vision to spot and pick ripe fruits and vegetables, which helps reduce food loss and damage.

But it doesn't stop there—robotic technologies are also shaking things up in livestock farming, fisheries, and food processing. Automated feeding and milking systems enhance livestock management, while AI-powered health monitoring minimizes the need for antibiotics and boosts animal welfare. In fisheries and aquaculture, underwater drones and robotic feeding systems optimize fish farming while helping to prevent overfishing. Lastly, robotics in food processing and supply chains streamline storage, packaging, and transportation, cutting down on food waste and ensuring efficient distribution.

As robotics continues to evolve, it's poised to play a vital role in creating climate-resilient, sustainable agriculture, providing solutions that harmonize food production with environmental conservation. The upcoming sections of this paper will

delve into the impact of robotics across various facets of food production, showcasing how automation is shaping the future of global food security.

ROBOTICS IN DIFFERENT ASPECTS OF FOOD PRODUCTION

1. Precision Agriculture: Enhancing Efficiency with Robotics

Precision agriculture is all about using data to make smart decisions that help farmers use resources like water, fertilizers, and pesticides more efficiently. Robotics is a game-changer in this field, automating tasks like monitoring fields, analyzing soil, and managing crops. One of the coolest advancements in precision agriculture is the introduction of autonomous tractors and drones. These high-tech machines come equipped with GPS, cameras, and sensors that help them navigate fields and assess soil health. Rather than spreading fertilizers or pesticides everywhere, AI-powered robots can pinpoint areas that need attention, applying treatments only where they're truly needed. This not only cuts down on chemical use but also helps protect our water sources and keeps the soil healthy. Another exciting development is in robotic weed control. Traditionally, weeding meant blanket applications of herbicides, which can harm the soil and disrupt local ecosystems. But now, modern AI-driven weeding robots use computer vision to tell crops apart from weeds. They can either pull weeds out mechanically or apply herbicides only where necessary. Some innovative robots, like laser weeders, even zap weeds with focused light beams, eliminating the need for any chemicals at all. These advancements are paving the way for a healthier environment and more sustainable farming practices.

2. Smart Irrigation and Water Conservation

Water is one of the most valuable and limited resources we have in agriculture. Unfortunately, traditional irrigation methods often waste a lot of water because they apply it without taking into account the moisture levels in the soil or the current weather conditions. Thankfully, robotics and AI-driven irrigation systems are changing the game when it comes to conserving water by providing just the right amount based on real-time data. These robotic

systems come equipped with soil moisture sensors and tools for analyzing climate data, allowing them to determine precisely when and how much water crops actually need. Rather than sticking to a rigid watering schedule, they adapt based on factors like temperature, humidity, rainfall predictions, and soil makeup. This smart approach helps prevent overwatering, which can cause root rot and nutrient depletion, while also cutting down water usage by as much as 50%. Drones are also stepping in to help monitor how well crops are hydrated. With their infrared imaging capabilities, drones can spot plants that are stressed from drought and identify specific areas that need extra irrigation. By promoting efficient water use, these robotic irrigation systems are playing a crucial role in tackling water scarcity and fostering sustainable farming practices.

3. Robotic Harvesting and Food Processing

Harvesting can be quite a demanding task, and it often leads to food waste because of inefficient picking techniques or delays. Many crops need to be harvested at just the right moment, and when there aren't enough workers, it can result in spoiled or damaged produce. That's where robotic harvesters come in! These machines, equipped with AI and machine vision, can spot ripe fruits and vegetables and pick them with incredible accuracy. Take strawberry-picking robots, for instance. They use sophisticated cameras and sensors to find ripe berries and gently pluck them, which helps avoid bruising. Apple-picking robots work similarly, using suction systems to gather fruits without causing any harm. These innovations not only speed up the harvesting process but also cut down on food waste while ensuring the produce remains top-notch. In the realm of food processing, robotics plays a crucial role in automating tasks like sorting, grading, and packaging. AI-driven systems evaluate the size, color, and texture of the produce, making sure that only the best items make it to the packaging stage. This approach not only reduces food waste but also boosts efficiency throughout the supply chain.

4. Robotics in Livestock Farming

Livestock farming plays a big role in greenhouse gas emissions and environmental harm.

However, robotics can step in to help lessen these effects by making feeding, health monitoring, and waste management more efficient. Automated feeding systems make sure that livestock get just the right amount of food, which cuts down on waste and boosts their nutrition. Smart sensors in feeding stations keep an eye on each animal's eating habits and adjust their food intake as needed, which helps prevent overfeeding and reduces methane emissions. Robotic milking machines are another exciting development that enhances efficiency while prioritizing animal welfare. These machines use gentle, automated methods to milk cows, which lowers their stress levels and increases milk production. Some of these robots can even analyze milk quality on the spot, spotting infections early and stopping diseases from spreading. AI-powered livestock health monitoring is yet another game-changer. Wearable sensors track vital signs, movement, and behaviour to catch sick animals before their symptoms worsen. This gives farmers the chance to take preventive action, cutting down on antibiotic use and boosting overall animal health.

5. Robotics in Food Supply Chain and Waste Reduction

Food waste is a huge problem around the world, with about a third of all the food we produce ending up in the trash. But here's where robotics comes in to save the day! By optimizing inventory management, streamlining logistics, and enhancing storage conditions, we can really make a difference in reducing waste. AI-powered inventory systems are great at analyzing trends in supply and demand, which helps prevent overproduction. Plus, smart warehouses equipped with robotic sorting and packaging systems ensure that food is stored just right, minimizing spoilage. On top of that, we're seeing the development of autonomous delivery robots and drones that can improve last-mile food distribution. This not only cuts down on transportation emissions but also helps get fresher food to consumers more quickly. By embracing robotics in our food supply chains, we can build a system that's not only more efficient but also less wasteful and kinder to the environment.

6. Precision Agriculture: Optimizing Crop Management with Robotics

Precision agriculture is all about using cutting-edge technology to make farming smarter, save resources, and boost crop yields. Unlike traditional farming, which often wastes water, uses too many pesticides, and spreads fertilizers inefficiently, precision agriculture takes a more thoughtful approach. By harnessing robotics, AI, and the Internet of Things (IoT), farmers can monitor their fields closely and intervene only when necessary, cutting down on waste and improving productivity. One of the standout uses of robotics in this field is automated field monitoring. Drones and ground robots, equipped with sensors and cameras, can assess soil health, track plant growth, and spot pest problems. With the help of AI algorithms, the data they gather is processed to give farmers real-time insights, allowing them to make smarter decisions. For example, instead of spraying pesticides across an entire field, robotic sprayers can zero in on the specific areas that need attention, which not only reduces chemical use but also helps protect the environment. Additionally, autonomous tractors and robotic seed planters are game-changers for efficiency. They ensure that seeds are planted accurately and in the best patterns possible. These machines leverage GPS and AI to adapt to different soil conditions, which helps maximize crop yields while using fewer resources. Robotic weeders, equipped with advanced computer vision, can spot and remove weeds without damaging the crops, eliminating the need for herbicides. By integrating robotics into precision agriculture, farmers can boost their productivity while minimizing their environmental footprint, paving the way for a more sustainable food system.

7. Smart Irrigation and Water Conservation

Water scarcity poses a significant challenge in agriculture, and the conventional irrigation methods we often rely on can lead to a lot of unnecessary water use. Thankfully, robotics and AI-driven irrigation systems are stepping in to tackle this problem by ensuring that water is distributed efficiently, all thanks to real-time data on soil conditions and weather. These smart irrigation systems are equipped with robotic sensors that are buried in the soil, constantly checking moisture levels, temperature, and humidity. The

information gathered is then processed by AI algorithms, which figure out exactly how much water each plant needs. Instead of dousing an entire field with water, these robotic systems target specific areas, cutting down water waste by as much as 50%. Plus, with weather prediction models built into these systems, they can tweak watering schedules based on forecasts for rain, making water use even more efficient. Drones are also becoming essential in keeping an eye on crop hydration. By using infrared imaging, they can spot areas in the fields that are stressed due to drought and suggest where to focus irrigation efforts. Robotic irrigation not only saves water but also helps prevent issues like soil erosion, nutrient loss, and root diseases, resulting in healthier crops and a more sustainable farming approach.

8. Automated Greenhouses and Controlled Environment Agriculture (CEA)

Greenhouses create a perfect little world for growing crops, shielding them from harsh weather and pesky pests. But let's be honest—keeping everything just right can be a real hassle and often takes a lot of time and effort. That's where robotics comes in, shaking things up in greenhouse farming with smart climate control, robotic pollination, and automated nutrient delivery systems. These high-tech greenhouse systems use AI-driven robots to keep an eye on and adjust temperature, humidity, light levels, and CO₂ concentrations. They're constantly fine-tuning the environment to help plants thrive, which means better harvests while using fewer resources. Plus, robotic pollinators, designed to act like bees, step in to ensure that pollination happens even in indoor settings where you won't find any natural pollinators buzzing around. In vertical farming and hydroponics, robotic arms take on the tasks of planting, pruning, and harvesting crops with incredible accuracy. Automated nutrient delivery systems make sure that plants get just the right amount of water and nutrients, cutting down on waste and boosting efficiency. By weaving robotics into greenhouse farming, we can grow food all year long while using 95% less water and relying much less on pesticides, making it a super sustainable choice compared to traditional farming methods.



9. Robotics in Livestock Farming and Dairy Production

Greenhouses create a perfect little world for growing crops, shielding them from harsh weather and pesky pests. But let's be honest—keeping everything just right can be a real hassle and often takes a lot of time and effort. That's where robotics comes in, shaking things up in greenhouse farming with smart climate control, robotic pollination, and automated nutrient delivery systems. These high-tech greenhouse systems use AI-driven robots to keep an eye on and adjust temperature, humidity, light levels, and CO₂ concentrations. They're constantly fine-tuning the environment to help plants thrive, which means better harvests while using fewer resources. Plus, robotic pollinators, designed to act like bees, step in to ensure that pollination happens even in indoor settings where you won't find any natural pollinators buzzing around. In vertical farming and hydroponics, robotic arms take on the tasks of planting, pruning, and harvesting crops with incredible accuracy. Automated nutrient delivery systems make sure that plants get just the right amount of water and nutrients, cutting down on waste and boosting efficiency. By weaving robotics into

greenhouse farming, we can grow food all year long while using 95% less water and relying much less on pesticides, making it a super sustainable choice compared to traditional farming methods.

10. Robotics in Fisheries and Aquaculture

The global fishing industry is grappling with some serious sustainability issues, like overfishing, bycatch, and habitat destruction. Thankfully, robotics is stepping in to help tackle these challenges by enhancing fish farming practices and making ocean fishing more sustainable. For instance, AI-powered underwater drones are now being deployed to keep an eye on fish populations and track endangered species, which helps fishing fleets steer clear of overexploited areas. Plus, robotic sorting systems on fishing boats are doing a great job of minimizing bycatch by identifying and safely releasing non-target species, which helps protect our marine ecosystems from unnecessary harm. In the realm of aquaculture, robotics is boosting the efficiency of fish farming. Automated feeding systems are designed to dispense just the right amount of food, cutting down on waste and preventing water pollution that can come from overfeeding. Meanwhile, AI-driven robots that

monitor water quality are constantly checking oxygen levels, pH, and temperature to ensure the best possible conditions for farmed fish. These innovative technologies not only lessen environmental impact but also promote healthier fish and improve production efficiency.

11. Robotics in Post-Harvest Handling and Food Processing

A large amount of food goes to waste between the time it's harvested and when it's actually consumed, mainly because of inefficiencies in storage, transportation, and processing. Thankfully, robotics is stepping in to tackle this problem by automating tasks like sorting, packaging, and managing cold storage. AI-powered sorting robots are equipped with computer vision technology that helps them assess the size, color, and texture of fruits and vegetables, making sure that only the best quality food makes it to consumers. These robots can spot and remove any defective items, which helps cut down on food waste. Plus, robotic packaging systems are boosting efficiency while also reducing plastic use by opting for sustainable packaging materials. Cold storage facilities are getting a makeover too, thanks to robotics. Smart robotic systems can adjust temperature and humidity levels to keep perishable food fresh for a longer time. AI-driven inventory management systems keep an eye on food expiration dates, helping to prevent spoilage and further reduce waste. All these robotic innovations are making a real difference in creating a more sustainable food supply chain.

Conclusion

Robotics is quickly changing the landscape of food production, offering efficient, resource-saving, and environmentally friendly solutions to tackle the increasing global food demands. By harnessing the power of AI, IoT, and machine learning, robotic systems are fine-tuning farming practices, cutting down on waste, boosting yields, and supporting eco-conscious agriculture.

From precision farming and smart irrigation to robotic harvesting, automated livestock management, sustainable fisheries, and streamlined food processing, robotics is making a remarkable difference across various sectors. One of the standout benefits of robotics is its knack for boosting productivity while using fewer resources. AI-powered agricultural robots fine-tune the application of fertilizers and pesticides, which helps minimize chemical runoff and keeps our soil healthy. Smart irrigation systems conserve water by delivering just the right amounts based on real-time data, tackling one of the biggest sustainability challenges in agriculture. Robotic harvesters help cut down on food waste by ensuring that crops are picked at their peak ripeness, while automated food processing and supply chain systems work to reduce spoilage and enhance logistics efficiency. However, despite its immense potential, the widespread use of robotics in agriculture comes with its own set of challenges. High upfront costs, the need for technical know-how, and ethical concerns about automation and job displacement are hurdles that need to be overcome. Yet, as technology continues to advance, the price of robotic systems is likely to drop, making them more accessible for farmers around the globe. It's crucial for governments, agricultural organizations, and tech developers to join forces in creating policies, subsidies, and training programs that support the integration of robotics into sustainable farming practices. To wrap things up, robotics is set to become a crucial player in the future of food production. It will help make agriculture more efficient, resilient, and eco-friendly. With the global demand for food on the rise, adopting robotic automation is essential for ensuring a sustainable and secure food future for the generations ahead.

AUTHORS' DETAILS:**Shruti Ranjan¹,****Nisha Jyoti¹,****Tanu Priya¹,****Rohini Kumari¹,****Nikki Kumari¹,****Eashan Mukherjee^{1*}**

¹Division of Agriculture, F/C:
Agriculture, Rural and Tribal
Development (ARTD),
Ramakrishna Mission
Vivekananda Educational and
Research Institute (RKMVERI),
Ranchi Campus, Jharkhand,
India.

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Micropropagation in Flowering Ornamentals**Introduction**

In commercial floriculture, ornamentals are the plants grown for aesthetic demand. Flowers are important due to their colour, scent and secondary metabolites which possess potential pharmacological and ethnobotanical uses. Flowering ornamentals like Rose (*Rosa sinensis*), Chrysanthemum (*Chrysanthemum cinerarifolium*), Periwinkle (*Catharanthus roseus*), Gerbera (*Gerbera jamesonii*), and Marigold (*Tagetes* sp.) exhibit brightly colored flowers bearing desirable shape, size, scent and aroma. The flowers used for religious, decoration, garland, loose flower purposes and landscaping. They form primary commodity in retail floristry, floral installations, and ceremonial bouquets. Compact and miniature genotypes are bred specifically for container gardening, patio ornamentation, and residential interior displays. Extensively deployed within corporate offices, public institutions, and display pavilions to enrich aesthetic design and promote biophilic benefits. These flowering plants are rich in various secondary metabolites which contribute to the pigment and flower colour in plants (Table 1). These secondary metabolites hold immense pharmacological and ethnobotanical potentials for the commercial floriculture industry. Traditional vegetative methods of propagation such as seeds, cuttings and vegetative clumps give low flower yield and incidence of diseases and pests. Simultaneously, seed propagation fails to preserve uniform agronomic qualities because outcrossing causes high genetic divergence which reduce the quality as well as secondary metabolite content of these crops. Hence, in this regard, *in vitro* micropropagation provides a reliable solution, generating uniform, disease free clonal plants at annual rates exceeding hundreds of thousands from limited initial stock. Micropropagation is based on the principle of cellular totipotency, according to which living plant cells possess the genetic potential to regenerate into a complete plant when provided with suitable nutritional, hormonal and environmental conditions.

Requirements for micropropagation

- **Explant Sources:** Apical and axillary shoot tips (0.5–1.0 cm), Leaf segments, nodal segments, capitulum sections or ray floret pieces (2–3 mm) (in case of Gerbera) excised from healthy greenhouse mother stock.
- **Disinfecting Agents:** Non-ionic surfactants (Tween-20 or Teepol at 2% v/v), 70% ethanol, and 0.1% (w/v) mercuric chloride or 20% sodium hypochlorite.
- **Nutrient Formulation:** Murashige and Skoog (1962) salt mixture is the most commonly used basal media. It is supplemented with 3% sucrose and 0.8% agar powder. The pH of the media is adjusted to pH 5.7–5.8.
- **Exogenous Regulators:**
 - Cytokinins: 6-Benzylaminopurine (BA), Kinetin,
 - Auxins: 2,4-Dichlorophenoxyacetic acid (2,4-D), Indole-3-acetic acid (IAA), and Indole-3-butyric acid (IBA).

Table 1: Botanical Name, Family, Secondary metabolites found in flowering ornamentals and their uses

Common Name	Botanical Name	Family	Secondary Metabolites	Uses of secondary metabolites
African Marigold (2n=2x=24)	<i>Tagetes erecta</i>	Asteraceae	Lutein, zeaxanthin, and β -carotene	Eye health and food colourants
French Marigold (2n=4x=48)	<i>Tagetes patula</i>	Asteraceae		
Periwinkle (2n=2x=16)	<i>Cathartus roseus</i>	Apocynaceae	Vinblastine, Vincristine	Anticancer properties
Rose (2n=4x=28)	<i>Rosa</i> spp.	Rosaceae	Citronellol, geraniol, linalool, nerol, and β -damascenone	Perfume and cosmetics, aromatherapy and
Gerbera (2n=2x=50)	<i>Gerbera jamesonii</i>	Asteraceae	Cyanidin- and pelargonidin-based anthocyanins, rutin, luteolin, apigenin, and quercetin glycosides	Antioxidant, anti-inflammatory, and antiproliferative (anticancer) activities
Chrysanthemum (2n=6x=54)	<i>Chrysanthemum morifolium</i>	Asteraceae	Pyrethrin I and II, cinerin I and II, and jasmolin I and II	Organic insecticides, antimicrobial and antifungal

Methodology

1. **Explant Harvest:** Actively growing vegetative shoot tips (0.5–1.0 cm) or young floral ray florets are collected from vigorous greenhouse stock plants.
2. **Cleaning & Decontamination:** The tissues are rinsed under flowing tap water for 10–15 minutes followed by washing with double distilled water. Next the explants are washed with 2% Tween-20 solution for 5 minutes, followed by treatment with 0.2% mercuric chloride solution (2-3 minutes) and 20% sodium hypochlorite solution (10–15 min). All surface sterilization activities should be carried out under aseptic conditions inside laminar airflow cabinet. Treatment with each sterilant should be followed by rinsing with sterile distilled water for two to three times.
3. **Culture Initiation:** The surface sterilized shoot apices are inoculated onto semi-solid MS medium supplemented with cytokinins like BAP and Kinetin (1.0 - 2.0 mg/L). Cytokinin promotes shoot initiation and multiplication. When micropropagation involves an intermediate callus phase it is called indirect regeneration. For induction of callus petal or leaf segments are placed on MS basal medium enriched with 2.0 mg/L 2,4-D in the dark. This mass of unorganized cells called callus is then induced with the help of different PGRs to differentiate into shoot.
4. **Shoot Proliferation:** The culture vessels are kept at $25 \pm 2^\circ\text{C}$ under 16-hour daily photoperiod (50–60 $\mu\text{mol}/\text{m}^2/\text{s}$). Subculture should be done every 4 weeks to obtain high-frequency multiplication.
5. **Root Induction:** Individual elongated shoots (4–5 cm) are transferred to a separate basal media containing MS supplemented with auxins like IAA or IBA or NAA (1.0 - 2.0 mg/L). Auxins promote root differentiation and formation.
6. **Ex Vitro Hardening:** The rooted plantlets are transferred into small sterilized plastic pots filled with sterilized manure, sand and soil

(1:1:1). Cocopeat – sand mixture (1:1) or vermiculite can also be used. The pots are covered with transparent polypropylene packets to preserve 85–90% relative humidity for 10–15 days, gradually venting to match ambient conditions.

7. Acclimatization & Field Transfer: Established, well-hardened plantlets displaying 5–6 expanded leaves are shifted into open greenhouse for cut flower and pot production.

Micropropagation Approaches in flowering ornamentals

Multiple *in vitro* regeneration pathways are employed according to propagation and breeding goals:

1. Shoot Tip Culture: Cultures meristematic apices on balanced cytokinin media. Considered the benchmark for commercial nurseries because direct organogenesis preserves genetic trueness-to-type.
2. Leaf and Petiole Regeneration: Explants from lamina or petioles can differentiate shoots directly or via callus under appropriate hormonal stimuli, providing ample starting material without damaging the main plant crown.
3. Callus-Mediated Culture: Undifferentiated cellular masses induced by auxins (such as 2,4-D) enable downstream *in vitro* selection, cell suspension culture, and targeted screening for somaclonal mutations.
4. Inflorescence & Receptacle Culture: Young capitulum disks and floret primordia are used to regenerate multiple adventitious shoots, maximizing explant yield per stem.
5. Embryo Culture: Zygotic embryo culture entails the aseptic excision of sexually fertilized embryos from the maternal ovary and their rearing on defined synthetic nutrient media.
 - Explant Source: Immature embryos dissected from developing achenes 10–14 days after controlled cross-pollination.

- Sterile Isolation: Precise micro-dissection of embryos under stereomicroscopic guidance inside a laminar airflow cabinet.
- Medium Inoculation: Transfer of intact embryos onto half-strength or basal MS medium without growth regulators or with light auxin/cytokinin balances.
- Seedling Germination: Rapid, unhindered embryonic germination into normal seedlings possessing balanced shoot and taproot systems.

Advantages of micropropagation in flowering ornamentals

- *In vitro* florigenesis achieved through micropropagation leads to continuous, year-round production of disease-free stock irrespective of weather.
- Maintains clonal uniformity and true-to-type plantlets for elite commercial cultivars. Genetically uniform plantlets display better vigour and floral characters preferable for commercial markets.
- Disease free plants can be produced.
- Increases mass multiplication as compared to conventional propagation.
- Shelf-life of flowering ornamentals increases as compared to field grown cuttings. This fetches better prices at market generating higher income and revenue.
- Enhancement in secondary metabolite content among *in vitro* regenerants leads to increased industrial and pharmacological utilizations.
- Provides for germplasm conservation
- Plant tissue culture provides invaluable regeneration prospect for genetic transformation and gene editing studies

Limitations

- High susceptibility of field-derived crown tissue to endogenous bacterial contamination.

- Exudation of polyphenol compounds can cause culture medium browning and tissue death.
- Callus-derived regenerants risk somaclonal variations in flower color or form.
- Demands high upfront capital for cleanroom air systems, autoclaves, and growth facilities.

Conclusion

Micropropagation is an important biotechnology for the rapid multiplication of flowering ornamentals. The major stages include explant selection, sterilization, culture initiation, shoot multiplication, shoot elongation, rooting, hardening and acclimatization. Shoot tip culture using apical and axillary meristems, *in vitro* florigenesis are particularly useful for obtaining clean planting material, while embryo culture provides an effective alternative for whole plant regeneration and biotechnological research. Callus cultures could be utilized to develop cell suspension cultures and indirect shoot regeneration which in turn provide for secondary metabolite biosynthesis. For commercial upliftments bioreactors provide viable units for phytometabolites production. Recent developments in flower genomics and regeneration-related genes have helped researchers understand and improve tissue-culture techniques.

AUTHORS' DETAILS:

Kavya V¹ ,
Nishanth C ²
Kotresh A.M³

¹ Assistant Professor Veterinary
College Hebbal, Bangalore.

² Veterinary Officer Ramuhalli,
Government of Karnataka

³ Professor and Head, Veterinary
College Hebbal, Bangalore

ARTICLE ID: 08

Biochemical and clinical Management of Milk Fever in High-Yielding Dairy Cows

Introduction

Metabolic diseases in cattle, such as hypocalcaemia, ruminal disorders, and ketosis, arise due to disruptions in normal metabolic processes. Dairy animals are more susceptible than other species because of their high production demands. High-yielding dairy cows, in particular, are at greater risk when feeding and management practices are inadequate. Improper nutrition can lead to a negative energy balance, a condition in which energy expenditure exceeds energy intake, predisposing animals to various metabolic disorders.

The transition period is the most critical stage for the development of these diseases. This phase extends from late pregnancy through calving and continues until peak lactation. During this time, the animal undergoes a rapid shift from a pregnant state to intensive milk production. This transition requires substantial energy for both fetal growth and lactogenesis. Consequently, dairy cows experience significant metabolic, endocrine, and nutritional changes, increasing their vulnerability to metabolic disorders. Several studies have shown that negative energy balance and metabolic stress are associated with disturbances in normal blood metabolites.

1. Milk Fever (Hypocalcaemia)

Hypocalcaemia, commonly known as milk fever, is one of the most prevalent metabolic diseases affecting high-producing dairy cows, particularly during the transition from calving to early lactation. Approximately 80% of cases occur within one week of calving, as the onset of colostrum and milk production results in a sudden and substantial loss of calcium from the bloodstream. This acute demand for calcium often exceeds the animal's physiological capacity to maintain normal blood calcium levels.

High-yielding breeds, especially Jersey cows, are more susceptible to hypocalcaemia compared to other breeds. There are many nutritional factors which is responsible for milk fever like decreased feed intake during calving, nutrition status of late pregnancy stage, increased calcium intake during parturition, increased phosphorus dietary intake, or dietary cation anion differences.

2. Regulation of Blood Calcium

Calcium is an essential mineral required for numerous physiological functions, including muscle contraction, nerve transmission, and milk production. Its concentration in the blood is tightly regulated by hormones, primarily parathyroid hormone (PTH) and calcitonin. A decrease in blood calcium levels stimulates the parathyroid gland to secrete PTH. This hormone plays a central role in restoring calcium homeostasis through multiple mechanisms. PTH enhances renal reabsorption of calcium, thereby reducing its loss through urine, while simultaneously decreasing phosphate reabsorption. It also stimulates the kidneys to convert 25-hydroxycholecalciferol into its active form, 1,25-dihydroxycholecalciferol (vitamin D₃), which increases intestinal absorption of calcium.

In addition, PTH, along with active vitamin D₃, promotes osteoclastic activity, leading to bone resorption and the release of calcium into the bloodstream. Through these coordinated actions—bone resorption, increased intestinal absorption, and reduced urinary loss—blood calcium levels are restored.

3. Nutritional approach for prevention of milk fever

1. Dietary Management (DCAD Management)

Proper feeding during the dry period is very important for preventing milk fever in dairy cows. During the close-up dry period, feeding a low-potassium diet (less than about 1.5% potassium) can help reduce the dietary cation–anion difference (DCAD). About 2–3 weeks before calving, anionic salts such as ammonium chloride and magnesium chloride can be included in the diet to produce a mild metabolic acidosis. This helps the body respond better to parathyroid hormone (PTH), which plays an important role in maintaining blood calcium levels. It promotes the release of calcium from the bones and improves calcium absorption from the intestine. These changes help the cow meet the sudden increase in calcium requirement at calving and reduce the risk of milk fever.

2. Controlled Dietary Calcium Intake

Restricting dietary calcium during the prepartum period can also help in preventing milk fever. Providing **less than 100 g of calcium per day** before calving increases the demand for calcium from the cow's own body and stimulates the mechanisms involved in calcium regulation. This helps the cow become better prepared to mobilize calcium from the bones and maintain normal blood calcium levels after calving. As a result, the cow can adapt more easily to the sudden increase in calcium requirement at the beginning of lactation, thereby reducing the risk of hypocalcaemia.

3. Oral Calcium Supplementation

Oral calcium supplements, such as **calcium boluses or calcium gels**, are commonly used around calving to help prevent milk fever. They are particularly useful in **older, multiparous cows and high-producing dairy cows**, which are at greater risk of developing hypocalcaemia. A commonly followed supplementation schedule is to give **one calcium bolus immediately after calving and a second bolus about 12 hours later**. In high-risk cows, an additional dose may be given after 24 hours when required. Oral calcium provides a readily available source of calcium during the period when the cow's demand is suddenly increased, helping to maintain blood calcium levels and reduce the risk of clinical milk fever.

4. Magnesium Supplementation

Magnesium also plays an important role in maintaining normal calcium levels in dairy cows. It is necessary for the **release and proper action of parathyroid hormone (PTH)**, which regulates calcium levels in the blood. Therefore, providing adequate magnesium during the transition period is important for preventing milk fever. Supplementation of around **15–20 g of magnesium per day**, depending on the animal's dietary requirement, can support normal calcium metabolism. Adequate magnesium improves the cow's response to PTH and helps maintain blood calcium levels, thereby reducing the risk of hypocalcaemia around calving.

AUTHORS' DETAILS:

Syed Hamza Syed
Saidoddin¹,
Nikhil Madhavrao
Salunke²

^{1&2} Assistant fisheries
development officer,
Latur Government of
Maharashtra

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“Fish Waste: From Environmental Burden to Economic Opportunity”

Introduction

The global fisheries and aquaculture sector is increasingly moving towards a **circular bioeconomy**, where fish are utilized more completely and processing residues are converted into useful products rather than being discarded. Global fisheries and aquaculture production reached a record **235 million tonnes in 2024**, increasing the importance of efficient utilization of aquatic resources. The FAO has highlighted the untapped potential of using whole fish and processing by-products to improve food security, nutrition and sustainability.

Fish processing generates substantial quantities of heads, frames, skin, scales, viscera, bones, fins, blood and trimming residues. Depending on species and processing method, approximately **50–70% of the fish biomass can become processing by-products**. These materials should not necessarily be considered waste because they contain valuable proteins, lipids, collagen, gelatin, minerals, enzymes, pigments and other bioactive compounds.

The concept of “**Fish Waste to Wealth**” therefore represents a shift from a conventional linear model—*catch → process → discard*—towards a circular model—*catch → process → recover → transform → reuse → generate value*. Such an approach can reduce environmental pollution while creating additional income opportunities for seafood processors, entrepreneurs, fishers and coastal communities.

From Processing Waste to Valuable Resources

Fish-processing by-products can be broadly classified into **edible and non-edible fractions**. Heads, frames, skin, bones, viscera, scales and trimmings may contain significant amounts of proteins, oils, minerals and structural biomolecules.

Major fish by-products and their potential uses

Fish by-product	Valuable components	Potential products
Head and frames	Protein, minerals, oil	Fishmeal, hydrolysates, stock, calcium products
Skin	Collagen, gelatin, protein	Collagen peptides, gelatin, biomaterials
Scales	Collagen, minerals	Collagen, hydroxyapatite, biomaterials
Bones	Calcium, phosphorus, collagen	Mineral supplements, hydroxyapatite
Viscera	Protein, enzymes, lipids	Enzymes, hydrolysates, silage, fertilizer
Trimmings	Protein, lipids	Fishmeal, protein hydrolysate, pet food
Fish oil fractions	EPA, DHA and other lipids	Feed, food, pharmaceutical and industrial products
Shellfish shells	Chitin and minerals	Chitin, chitosan, agricultural and biomedical products

Recent reviews have identified collagen, gelatin, protein hydrolysates, chitin, chitosan, polyunsaturated fatty acids, enzymes, minerals and pigments as important value-added products that can be recovered from seafood processing residues.

Innovations Turning Fish Waste into Wealth

1. Fish Protein Hydrolysates and Bioactive Peptides

One of the promising technologies is the production of **Fish Protein Hydrolysate (FPH)**. Proteins recovered from fish heads, frames, skin, viscera and trimming waste can be broken down into smaller peptides using enzymatic, chemical or microbial hydrolysis.

FPHs can have desirable nutritional and functional characteristics and have potential applications in **functional foods, nutraceuticals, animal feed and aquaculture diets**. Research has also investigated their antioxidant and other bioactive properties.

Modern extraction technologies—including ultrasound-assisted extraction, microwave-assisted extraction, membrane processes and other advanced techniques—are being investigated to improve recovery efficiency and product quality.

2. Fish Collagen and Gelatin

Fish skin, scales and bones are important sources of **collagen**, a structural protein with applications in food, cosmetics, nutraceuticals and biomedical materials.

Collagen can be processed into collagen peptides or gelatin. Marine-derived collagen has attracted interest as an alternative source of collagen because seafood processing residues provide a readily available raw material.

Potential applications include:

- Functional food ingredients
- Nutraceutical products
- Cosmetics and personal-care products
- Pharmaceutical formulations
- Wound-care and biomedical materials
- Edible films and biodegradable materials

Thus, a discarded fish skin or scale can potentially become a **high-value industrial ingredient**.

3. Fish Oil: From By-product to Functional Resource

Fish-processing residues can also provide valuable oils containing **long-chain polyunsaturated fatty**

acids, including EPA and DHA. Fish oil recovered from suitable processing by-products can be utilized in food, feed, pharmaceutical and industrial applications. Recent research has focused not only on oil extraction but also on improving its **purity, oxidative stability, shelf life and functional properties**.

Efficient recovery of oil can therefore create an additional revenue stream while reducing the quantity of organic material requiring disposal.

4. Fishmeal, Fish Silage and Aquaculture Feed

Fishmeal remains one of the established routes for utilizing fish-processing residues. Heads, frames, trimmings and other suitable materials can be processed into protein-rich feed ingredients.

Another approach is **fish silage**, produced through controlled acidification or fermentation of fish residues. It can be incorporated into animal and aquaculture feed systems when produced under appropriate quality and safety conditions.

However, the emerging focus is increasingly on moving beyond conventional low-value products and recovering **higher-value proteins, peptides, collagen and other bioactive compounds**. A 2024 review noted that substantial quantities of fish processing residues are still directed towards comparatively low-value products, highlighting the opportunity for higher-value valorization.

5. Chitin, Chitosan and Shellfish By-products

Shrimp, crab and other crustacean processing generate large quantities of shells and exoskeletons. These materials contain **chitin**, which can be converted into **chitosan**.

Chitin and chitosan have diverse applications in:

- Food packaging
- Water treatment
- Agriculture
- Biodegradable materials
- Cosmetics
- Pharmaceutical applications
- Biomedical materials

The recovery of chitin and chitosan demonstrates that seafood processing residues can serve as raw materials for industries far beyond conventional fisheries and food production.

6. Fish Waste for Agriculture and Biofertilizer

Not every fraction of fish waste needs to enter the human food chain. Materials unsuitable for food-grade applications can potentially be processed into **fish fertilizer, compost or other agricultural inputs**, subject to appropriate processing and regulatory requirements.

Fish-based fertilizers contain nutrients and organic matter that can contribute to soil fertility. FAO identifies the valorization of fish-processing by-products into **food ingredients, feed, fertilizer and other high-value products** as part of the broader sustainable bioeconomy.

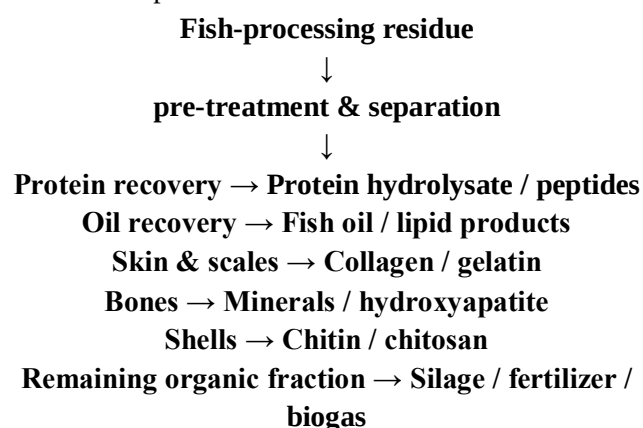
This creates an opportunity to establish a local circular system:

Fish processing → by-products → fertilizer → crop production → local food system

Emerging Technologies: The Seafood Biorefinery

The future of fish-waste utilization lies in the development of an integrated **seafood biorefinery**.

Instead of processing all residues into one product, different components can be separated and converted into several products:



Recent research describes this multi-product approach as an important direction for circular and sustainable utilization of marine by-products.

Advanced techniques such as **enzymatic hydrolysis, fermentation, ultrasound-assisted extraction, microwave-assisted extraction, membrane separation and supercritical-fluid extraction** are being investigated to improve recovery of valuable compounds

Environmental and Economic Benefits

The conversion of fish waste into useful products

provides several potential benefits.

Environmental benefits

- Reduction in organic waste entering landfills and water bodies
- Lower pollution associated with uncontrolled disposal
- Better utilization of harvested aquatic resources
- Reduction in resource wastage
- Contribution to circular-economy approaches

Economic benefits

- Creation of new value chains
- Additional income for processors and entrepreneurs
- Development of small and medium-scale enterprises
- Opportunities for women and rural/coastal self-help groups
- New employment in collection, processing, packaging and marketing

Food and nutritional benefits

Recovering proteins and other nutrients from suitable processing fractions can increase the amount of useful nutrition obtained from aquatic resources. FAO's Blue Transformation approach emphasizes improved utilization of aquatic foods and by-products as part of sustainable food systems.

Challenges and the Way Forward

Despite its considerable potential, fish-waste valorisation faces several challenges. Fish-processing residues are **highly perishable**, and delays between processing and recovery can reduce raw-material quality. Their composition also varies according to species, season, processing method and storage conditions.

Other challenges include:

1. **Collection and segregation** of different by-products.
2. **Cold-chain and storage requirements** to prevent deterioration.
3. **High initial investment** for extraction and processing equipment.
4. **Food-safety and regulatory requirements** for products intended for human consumption.

5. **Technical expertise** for advanced extraction technologies.
6. **Market development** for new value-added products.
7. **Economic feasibility and scale-up** from laboratory research to commercial production.

Future development should therefore focus on decentralized processing facilities, improved cold-chain infrastructure, technology transfer, quality standards, skill development and stronger links between **research institutions, fisheries departments, seafood industries, entrepreneurs and fishing communities.**

Conclusion: A New Meaning for “Waste”

The idea of “**Fish Waste to Wealth**” challenges the traditional perception that fish heads, skin, bones, scales and viscera are merely waste materials. They can instead be viewed as **secondary raw materials containing proteins, oils, collagen, minerals, enzymes and other valuable compounds.**

The seafood industry is gradually moving towards a model in which maximum value is obtained from every part of the fish. Conventional products such as fishmeal, fish oil and silage can be complemented by higher-value products such as **protein hydrolysates, bioactive peptides, collagen, gelatin, chitin, chitosan, nutraceutical ingredients and biomaterials.**

The ultimate goal is not simply to manage waste, but to **eliminate the concept of waste wherever possible.** Through innovation, biotechnology and circular-economy thinking, seafood-processing residues can become new sources of food, feed, fertilizer, materials, employment and income.

“The fish of the future is not only the fish we eat—it is the complete resource we utilize.”

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AUTHORS' DETAILS:

Dr. T. Bharath

Senior Scientist & Head
Krishi Vigyan Kendra,
Bhadravadi Kothagudem

ARTICLE ID: 10

Crop Diversification: A Sustainable Path for Soil, Water and Environmental Conservation

Introduction

Agriculture is the backbone of rural livelihoods, but continuous cultivation of the same crop year after year can gradually reduce soil fertility, increase pest and disease problems, and place greater pressure on water resources. **Crop diversification** offers a practical and sustainable solution. It means growing a variety of crops—such as cereals, pulses, oilseeds, vegetables, fodder crops and horticultural crops—either in rotation, intercropping or through multiple-cropping systems. Crop diversification is not only a strategy for increasing farm income; it is also an important tool for **conserving soil and water, improving biodiversity, reducing chemical inputs and protecting the environment.**

What is Crop Diversification?

Crop diversification involves moving from dependence on a single crop or cropping system to a combination of different crops suited to the local climate, soil and available water.

For example:

- Rice → Pulses or oilseeds
- Cotton → Pulses or oilseeds
- Maize → Sunflower/pulses
- Cereals + Pulses → Intercropping
- Crop + Horticultural crops → Integrated farming

The choice of crops should be based on **soil type, rainfall, irrigation availability, market demand and farmers' resources.**

1. Crop Diversification Improves Soil Health

Continuous cultivation of one crop can remove the same nutrients from the soil repeatedly. Diversification breaks this cycle. **Pulses such as red gram, green gram, black gram and chickpea** have an important role because they can fix atmospheric nitrogen through symbiotic association with *Rhizobium* bacteria. This helps improve soil nitrogen availability and can reduce dependence on external nitrogen fertilizers. Different crops also have different root systems. Deep-rooted crops can explore nutrients and moisture from deeper soil layers, while shallow-rooted crops utilize the upper soil layer. This creates more balanced nutrient utilization.

Benefits to soil include:

- Improved soil organic matter
- Better nutrient cycling
- Improved soil structure
- Increased microbial activity
- Reduced nutrient depletion
- Better soil fertility over time

2. Conserves Water

Water is one of the most important limiting resources in agriculture. Crop diversification allows farmers to select crops according to **available water and rainfall**. Instead of growing water-intensive crops continuously, farmers can include crops that require comparatively less water, such as pulses and oilseeds.

Practices such as:

- Mulching
- Conservation tillage
- Crop residue management
- Farm ponds
- Drip irrigation
- Rainwater harvesting
- Drought-tolerant crops

can further improve water-use efficiency.

“More crop per drop” can become a practical principle when crop selection is matched with available water resources.

3. Reduces Soil Erosion

A diversified cropping system provides better ground cover than a monocropping system. Crops with different canopy structures and root systems protect the soil from direct raindrop impact. Crop residues left on the soil surface act as a protective layer and reduce:

- Soil erosion
- Runoff
- Moisture loss
- Soil crusting

Cover crops and intercrops are particularly useful in reducing erosion during periods when the main crop does not provide sufficient ground cover.

4. Reduces Pest and Disease Problems

Growing the same crop continuously can create favourable conditions for crop-specific pests and diseases. Crop rotation disrupts their life cycles. For example, including a non-host crop between two seasons of the same crop can reduce the buildup of certain pests and pathogens.

Diversification also supports **Integrated Pest Management (IPM)** by encouraging beneficial insects and natural enemies. Thus, crop diversification can help reduce unnecessary pesticide applications and lower production costs.

5. Supports Environmental Protection

Agriculture and the environment are closely connected. Excessive use of fertilizers, pesticides and irrigation water can affect soil, water and biodiversity. Crop diversification can contribute to environmental protection by:

- Reducing excessive fertilizer use
- Reducing pesticide dependence
- Improving soil carbon storage
- Supporting beneficial insects
- Increasing on-farm biodiversity
- Reducing nutrient losses
- Improving ecosystem resilience

Agroforestry and integration of trees with crops can provide additional benefits such as carbon sequestration, wind protection, biodiversity conservation and additional farm income.

6. Helps Reduce Chemical Fertilizer Requirement

A diversified system allows farmers to integrate crops with complementary nutrient requirements. Inclusion of legumes is particularly valuable.

For example:

Cereal + Pulse → Better nutrient cycling → Improved soil fertility → Reduced dependence on external inputs

However, fertilizer requirements should always be determined through **soil testing and crop-specific recommendations** rather than assuming that diversification alone eliminates fertilizer requirements.

7. Improves Biodiversity

Monocropping creates a relatively uniform agricultural ecosystem. Crop diversification introduces different plants, flowering periods, root systems and habitats.

This can support:

- Pollinators
- Earthworms
- Beneficial insects
- Soil microorganisms
- Birds and other farm biodiversity

Greater biodiversity can make agricultural ecosystems more resilient to climatic and biological stresses.

8. Climate-Resilient Agriculture

Climate variability is increasing the risk of droughts, heavy rainfall, heat stress and pest outbreaks. Depending entirely on one crop can expose farmers to greater production risk. Diversification spreads this risk. If one crop is affected by drought or a pest outbreak, another crop in the system may perform relatively better.

Crop diversification + Soil health + Water conservation + Biodiversity = Climate-resilient agriculture

9. Improves Farmers' Income Opportunities

Crop diversification can provide farmers with multiple sources of income. Pulses, oilseeds, vegetables, fruits, fodder and livestock can be integrated according to local conditions and market opportunities.

For example, a farmer can combine:

Food crop + Pulse + Oilseed + Horticultural crop + Livestock

Such systems can provide income at different times of the year and reduce dependence on a single commodity. However, diversification should be **market-oriented**. Farmers should consider local demand, storage, processing, price fluctuations and access to markets before selecting alternative crops.

Suitable Diversification Approach for Rainfed Areas

In rainfed regions, diversification should focus on crops that can efficiently utilize available rainfall. A suitable approach can include:

Millets + Pulses + Oilseeds + Fodder crops

For example:

- Sorghum + Red gram
- Maize + Red gram
- Groundnut + Red gram
- Cotton + Pulses
- Maize → Sunflower/pulse rotation

The exact combination should be selected according to local soil, rainfall, irrigation and market conditions.

Role of Farmers and Extension Agencies

Successful crop diversification requires proper technical guidance. Extension agencies, KVKs, agricultural universities and line departments can support farmers through:

- Soil testing and soil health management
- Demonstration of diversified cropping systems
- Promotion of suitable high-yielding varieties
- Training on water-saving technologies
- Integrated nutrient management
- Integrated pest management
- Promotion of farm ponds and rainwater harvesting
- Market and value-addition support
- Farmer field demonstrations
- Encouraging farmer producer organizations and collective marketing

Conclusion

Crop diversification is more than simply growing different crops—it is a strategy for building healthy soils, conserving water, protecting biodiversity and creating resilient farming systems. By combining crop rotation, intercropping, pulses, oilseeds, conservation agriculture, efficient irrigation, residue management and integrated nutrient and pest management, farmers can improve resource-use efficiency while protecting the natural resource base.

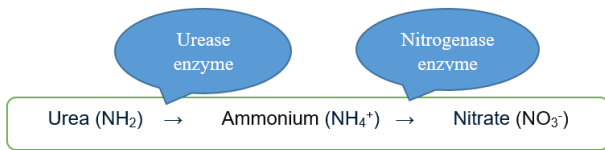
The future of sustainable agriculture depends not only on producing more food but also on producing it while using less water, maintaining soil fertility, protecting biodiversity and reducing environmental degradation.

AUTHORS' DETAILS:**Dr. Jarupula Suman***Assistant Professor,
School of Agricultural Sciences,
Anurag University, Hyderabad***ARTICLE ID: 11****LACK OF AWARENESS: AGRICULTURAL LANDS IN A
HELPLESS STATE**

Food security is a top priority for every nation. To ensure this, countries implement various policies that make chemical fertilizers available for agriculture at the right price and time, thereby boosting crop production. India, now the world's most populous nation, is an agrarian country. After the green evolution introduced high-yielding varieties to the market, leading to a significant increase in the use of chemical fertilizers. Rural farmers in India often perceive the application of commercial fertilizers as the primary means of increasing crop yields. However, excessive and indiscriminate use of these fertilizers can adversely affect soil health, disrupt soil ecological processes, and ultimately contribute to the deterioration of the entire soil ecosystem. Chemical fertilizer consumption in India stands at 70.7 million tonnes, growing at an annual rate of 9.1%; urea accounts for 38.77 million tonnes of this total, serving as the indispensable backbone of Indian agriculture. This reliance stems from the fact that nitrogen is a crucial macronutrient and a non-mineral element. There are two primary ways to introduce nitrogen into the soil: 1. Biological nitrogen fixation, and 2. Chemical fertilizers. For biological nitrogen fixation to occur, the soil must contain organic matter.

Typically, the use efficiency of nitrogen fertilizers does not exceed 40%; consequently, 60% of the applied nitrogen fertilizer remains unavailable to the crops. Notably, urea a commonly used nitrogen fertilizer contains only 46% nitrogen, with the remaining 54% consisting of salts. Excessive use of these nitrogen fertilizers has adverse effects on the soil. Chemical fertilizers cause certain types of salts to accumulate in the soil; as the concentration of these salts rises, the soil loses its natural properties. Consequently, the availability of naturally occurring soil nutrients diminishes. Key adverse effects include the formation of a white, salty crust on the surface, which alters the soil's nature, leading to issues such as acidification, salinization (becoming saline or alkaline), and drying out. This prevents crops from accessing the soil's natural nutrients.

For instance, nitrogen fertilizers in India are commonly available in the form of urea. In urea, nitrogen exists as an amide (NH_2), a form that plants cannot absorb directly. Plants can only assimilate nitrogen in two forms: nitrate (NO_3^-) and ammonium (NH_4^+). With the exception of paddy (rice), all other crops absorb nitrogen exclusively in the nitrate (NO_3^-) form. After urea is applied to the soil, specific microorganisms aided by the enzyme urease convert it into nitrate (NO_3^-) over a period of time (Fig. 1). The conversion of urea into ammonia requires the urease enzyme, which is produced by certain soil bacteria. Subsequently, the conversion of ammonia into a form accessible to plants requires the nitrogenase enzyme; this enzyme is also produced by specific types of bacteria. Therefore, to improve the use efficiency of nitrogen fertilizers applied to crops, it is essential to enhance soil biodiversity.



(Fig. 1) Transformation of Urea in the soil

A primary reason for the decline in soil biodiversity is the reduction of organic matter content, which deprives soil microorganisms of their energy source. Factors contributing to this decline in organic matter include: 1. Climate change (specifically rising daytime temperatures), 2. Intensive farming, 3. Reduced use of organic fertilizers, 4. Use of pesticides and herbicides, and 5. Deep ploughing. To enhance soil biodiversity, farmers should adopt the following management practices: 1. Incorporating crop residues into the soil by ploughing after the harvest season each year; 2. Applying 10–15 tonnes of farmyard manure per hectare annually; 3. Practicing crop rotation; 4. Using green manures; 5. Using biochar; and 6. Applying chemical fertilizers according to specific crop growth stages. For instance, crops require phosphorus primarily during the initial stage because it plays a crucial role in root system development; similarly, the need for nitrogen is lower during the early stage but higher during the vegetative growth phase.

AUTHORS' DETAILS:

B. R. Vasavi Devi*¹,

Udit Joshi¹,

Vaidehi

panchawatkar¹,

Ashutosh Dhasmana²,

Suripogula Sunil

Kumar²

¹Ph.D Scholar,

Department of Vegetable Science,

GBPUA&T, Pantnagar,

U.S. Nagar - 263 145,

Uttarakhand, India

² M.Sc Student,

Department of Vegetable

Science, GBPUA&T,

Pantnagar, U.S. Nagar - 263 145,

Uttarakhand, India

ARTICLE ID: 12

Advances in Cucumber Breeding: From Conventional Methods to Genomics-Assisted Approaches

Abstract

Cucumber (*Cucumis sativus* L.) breeding has advanced from conventional selection and hybridization toward increasingly precise, genome-informed strategies. Early breeding efforts centered on improving yield, fruit quality, sex expression, parthenocarp, and stress resistance through phenotypic selection, combining-ability analysis, and heterosis exploitation. The subsequent development of molecular markers enabled more efficient evaluation of genetic diversity, linkage analysis, QTL mapping, and marker-assisted selection. Sequencing of the cucumber genome further reshaped breeding practice by supplying a genomic framework for gene discovery, high-density marker development, and characterization of genetic variation. More recent progress in genome-wide association studies, genomic selection, transcriptomics, and functional genomics has enhanced the capacity to dissect complex traits and predict breeding value. In parallel, CRISPR/Cas-based genome editing has opened avenues for targeted modification of genes controlling disease resistance, plant architecture, and other agronomically valuable traits. Integrating these technologies with conventional phenotyping and hybrid breeding is giving rise to a more precise and efficient breeding pipeline. Future advances will hinge on combining high-throughput phenotyping, pan-genomic resources, multi-omics data, and predictive breeding with targeted gene modification. Such integration holds promise for accelerating the development of cucumber cultivars with enhanced productivity, fruit quality, stress resilience, and adaptability to evolving production systems, all while preserving the core principles underlying conventional breeding.

Keywords: Cucumber breeding; Genomic selection; Marker-assisted selection; CRISPR/Cas genome editing; Functional genomics

Introduction

Cucumber (*Cucumis sativus* L.) is one of the most widely cultivated vegetable crops worldwide, valued for both fresh consumption and pickling and produced extensively under open-field as well as protected cultivation systems. In addition to its nutritional and economic importance, cucumber has emerged as an important model crop for studying fundamental aspects of plant biology, particularly sex expression, reproductive development and vascular biology. A major milestone in cucumber research was achieved in 2009 with the sequencing of its genome, which represented the first complete genome sequence reported for a vegetable crop. The genome was assembled using a combination of Sanger and next-generation Illumina sequencing technologies and was estimated to contain seven chromosomes and 26,682 protein-coding genes (Huang *et al.*, 2009).



Availability of this reference genome substantially expanded the understanding of the genetic basis of important cucumber traits, including sex expression, disease resistance and fruit development, while providing a foundation for the development of genomics-assisted breeding approaches.

Since then, cucumber improvement has progressively expanded beyond conventional approaches such as pedigree selection and line $\times$ tester breeding to incorporate molecular markers, quantitative trait locus (QTL) mapping, genomic selection and genome editing. These technologies have enabled breeders to identify, track and manipulate genomic regions associated with agriculturally important traits with greater precision and efficiency (Kaur & Sharma, 2022). Advances in high-density genetic mapping and map-based gene discovery across cucurbit crops have further strengthened the molecular resources available for cucumber improvement (Wang *et al.*, 2024). Together, these developments reflect a transition from predominantly phenotype-driven breeding toward an integrated approach in which field evaluation, molecular information and genomic technologies collectively guide the development of improved cucumber cultivars.

Conventional Breeding Approaches: A Brief Background

Prior to the integration of molecular and genomic technologies, cucumber improvement was driven primarily by phenotypic selection, inbreeding and controlled hybridization. These conventional approaches established the foundation of modern cucumber breeding and continue to remain relevant, increasingly being integrated with molecular and genomic tools for more precise selection.

Pedigree and Pure-Line Selection

Pedigree selection has traditionally been employed to develop genetically uniform and homozygous cucumber lines through successive generations of self-pollination, accompanied by systematic selection for desirable traits. The resulting stabilized lines serve as valuable parental material for subsequent hybridization and cultivar development programmes.

Line $\times$ Tester Analysis and Combining Ability Studies

Line $\times$ tester analysis is an established mating design in cucumber breeding for assessing the combining ability of parental lines and cross combinations. It enables estimation of general combining ability (GCA), which primarily reflects the contribution of additive genetic effects, and specific combining ability (SCA), which is associated largely with non-additive genetic effects. Early studies involving gynoecious and monoecious female parents crossed with multiple male testers demonstrated the usefulness of this approach for identifying promising general combiners (Hormuzdi & More, 1989). Subsequent investigations involving diverse parental combinations have frequently reported a predominant contribution of non-additive gene action for fruit yield and several yield-associated traits, highlighting the relevance of hybrid breeding in cucumber improvement (Mule *et al.*, 2012). Similar combining-ability studies have been employed in different breeding programmes to identify superior parental combinations for yield and its component traits

(López-Sesé *et al.*, 2002). More recently, studies involving gynoecious cucumber lines at GBPUAT, Pantnagar, have applied line $\times$ tester analysis to assess combining ability and heterosis for earliness and yield-related traits, further demonstrating the continued relevance of this approach in contemporary cucumber breeding (Bisht *et al.*, 2025).

Heterosis Breeding in Cucumber

Heterosis breeding exploits the enhanced performance of F_1 hybrids resulting from the combination of genetically diverse parental lines. It has played a central role in cucumber improvement, particularly for increasing fruit yield, earliness and other commercially important traits. Numerous field evaluations have reported significant heterosis for yield and its component characters, with selected hybrids outperforming their parental lines and, in several cases, commercial standards. The consistent expression of hybrid vigour for economically important traits has contributed substantially to the widespread adoption of F_1 hybrid cultivars in commercial cucumber production.

Breeding for Key Horticultural and Agronomic Traits

Cucumber breeding objectives have progressively broadened from yield alone to the integrated improvement of productivity, fruit quality, reproductive efficiency, and environmental adaptability. Yield, governed chiefly by fruit number, fruit weight, earliness, and harvest duration, remains central but is complicated by its quantitative inheritance and genotype–environment interaction. Combining-ability analyses have therefore been extensively employed to identify superior parents and hybrid combinations, with significant GCA and SCA effects confirming the joint contribution of additive and non-additive gene action and supporting integrated selection–heterosis strategies (Sarkar & Sirohi, 2010; Pati *et al.*, 2015; Bhutia *et al.*, 2017). Fruit quality encompassing size, shape, colour, firmness, texture, and bitterness — has emerged as an

equally critical breeding target, enabling development of market-specific cultivars without compromising productivity. Reproductive traits are especially consequential given the strong dependence of fruit set on sex expression; gynoecious lines, predominantly bearing female flowers, have thus become key genetic resources for hybrid and yield-efficient cultivar development.

Parthenocarpy constitutes a further priority, particularly for protected cultivation where pollination is unreliable. This trait is quantitatively controlled and polygenic, with QTL mapping and genome-wide analyses identifying loci governing parthenocarpic fruit set (Wang *et al.*, 2016; Wang *et al.*, 2022). Subsequent work has linked natural parthenocarpic variation to specific favourable alleles and regulatory genes, reflecting a shift toward molecular dissection of this classically phenotypic trait (Zhu *et al.*, 2026). Disease resistance and stress tolerance have similarly gained prominence, though their expression is often stage- and environment-dependent, necessitating rigorous phenotypic screening across diverse germplasm. The compounding complexity of these quantitative traits has increasingly underscored the utility of genetic mapping and molecular data. Collectively, conventional breeding has generated considerable genetic diversity for yield, quality, and reproductive traits, yet the growing complexity of breeding goals now demands greater selection precision. The identification of genomic regions, candidate genes, and favourable alleles offers a means of complementing field-based selection with molecular tools, marking a transition toward genomics-assisted cucumber breeding.

Molecular Marker-Assisted Breeding in Cucumber

The constraints inherent to phenotype-based selection especially for traits exhibiting quantitative inheritance and pronounced environmental sensitivity catalyzed the incorporation of molecular markers into cucumber breeding programs. Early-generation marker systems, including RAPD, AFLP, and RFLP, laid the groundwork for genetic mapping, while SSR

markers subsequently offered greater reliability for diversity assessment, linkage mapping, and trait-based selection. The advent of cucumber genome sequencing further propelled marker development, enabling the discovery of abundant SSR and SNP resources and facilitating construction of high-density genetic maps (Huang *et al.*, 2009). These genomic resources have, in turn, enabled the identification of numerous QTLs and associated markers spanning yield, fruit characteristics, sex expression, parthenocarpy, and disease resistance. Markers linked to the F locus, for instance, have enabled early-stage selection of gynoecious individuals, while investigations into the CsACS1/CsACS1G gene have elucidated the genetic and ethylene-dependent mechanisms governing sex determination (Miao *et al.*, 2011; Knopf & Trebitsh, 2006). Correspondingly, QTL mapping efforts have delineated genomic regions implicated in resistance to downy and powdery mildew, offering viable targets for marker-assisted selection (Lu *et al.*, 2014; Wang *et al.*, 2020).

The expanding availability of SNP markers alongside high-throughput genotyping platforms has substantially enhanced both the resolution and efficiency of molecular breeding approaches. Genotyping-by-sequencing, in particular, has broadened the marker repertoire available for diversity evaluation, linkage analysis, and QTL discovery, thereby reinforcing the incorporation of genomic data into breeding pipelines (Verma *et al.*, 2022). Collectively, these advances have transformed cucumber improvement from a discipline reliant solely on phenotypic evaluation into one increasingly informed by genomic data establishing the conceptual and technical foundation for the subsequent emergence of genomics-assisted and precision-breeding methodologies.

Cucumber Genome: A Turning Point in Breeding

The completion of cucumber genome sequencing constituted a pivotal shift toward genome-enabled breeding. The inaugural reference genome, reported by Huang *et al.* (2009), spanned

approximately 203.9 Mb across seven chromosomes, furnishing a critical foundation for systematic gene discovery, comparative genomic analysis, and marker development. Subsequent resequencing initiatives revealed considerable genomic diversity among cucumber accessions, contributing to the identification of genomic regions implicated in domestication and agronomically significant traits (Lv *et al.*, 2012; Qi *et al.*, 2013). The emergence of refined genome assemblies and pan-genomic resources has further extended the capacity to capture genetic variation transcending a single reference sequence, thereby facilitating discovery of novel alleles and candidate genes. Collectively, these developments have propelled cucumber breeding beyond reliance on individual markers toward comprehensive genome-wide characterization, establishing the framework for GWAS, genomic selection, transcriptomic analysis, and other genomics-assisted strategies aimed at achieving greater precision in crop improvement.

Genomics-Assisted Breeding

The convergence of reference genome availability and high-throughput genotyping technologies has redirected cucumber breeding from marker-assisted selection toward genome-wide analytical frameworks. Genome-wide association studies (GWAS) capitalize on naturally occurring variation across diverse germplasm collections to pinpoint genomic regions and candidate genes underlying complex trait expression. Within cucumber, GWAS methodology has been deployed across fruit morphology, flowering behavior, sex expression, disease resistance, and other agronomically relevant characteristics, permitting interrogation of the genetic architecture underlying quantitative variation at considerably enhanced resolution (Qi *et al.*, 2013; Wóycicki *et al.*, 2011). Genomic selection (GS) constitutes a further methodological advance, leveraging genome-wide marker data to predict individual breeding values without necessitating prior association of each genomic segment with a discrete trait. This strategy proves especially pertinent for complex traits

governed by numerous loci of small effect, offering potential to compress breeding cycles through earlier identification of superior candidates (Crossa *et al.*, 2017). The growing availability of dense SNP datasets alongside extensive germplasm diversity in cucumber increasingly positions the crop for implementation of such predictive breeding frameworks.

Genomic technologies have concurrently reinforced transcriptomic and functional genomic approaches, enabling breeders to progress beyond mere genomic region identification toward mechanistic understanding of genes and biological pathways governing key traits. RNA sequencing and gene-expression profiling have illuminated pathways underlying sex expression, fruit development, disease resistance, and abiotic stress responses. The integration of genomic, transcriptomic, and phenotypic datasets thus furnishes a more holistic framework for identifying favourable alleles and expediting their deployment within breeding pipelines. Collectively, GWAS, genomic selection, and functional genomics are reshaping cucumber improvement transitioning the discipline from trait-by-trait selection toward genome-wide prediction and gene-informed breeding, thereby establishing the groundwork for the next generation of precision breeding strategies.

Gene Discovery and Functional Genomics

Progress in cucumber genomics has increasingly permitted breeders to transcend the mere localization of genomic regions, advancing instead toward identification of the genes and biological pathways governing agronomically important traits. Functional genomics achieves this by integrating genome sequence data, gene-expression profiles, and genetic analyses to characterize candidate genes underlying plant architecture, sex expression, fruit development, disease resistance, and stress responsiveness. This approach has proven particularly illuminating for sex determination, wherein genes implicated in ethylene biosynthesis and signal transduction have clarified the genetic mechanisms

regulating male and female flower development (Knopf & Trebitsh, 2006; Mibus & Tatlioglu, 2004).

Transcriptome-based investigations have further broadened the scope of gene discovery by revealing differentially expressed genes and regulatory networks associated with fruit development, parthenocarpy, and responses to pathogenic and environmental stresses. The integration of transcriptomic data with QTL mapping and genome-wide association analysis consequently sharpens candidate-gene prioritization and reinforces the linkage between genotype and phenotype.

A particularly consequential development has been the functional validation of candidate genes through reverse-genetic strategies and genome-editing technologies. CRISPR/Cas-based systems now permit precise, targeted modification of genes underlying economically significant traits, offering a direct experimental means of interrogating gene function and generating novel allelic diversity. Within cucumber, genome editing has been successfully applied to traits spanning sex expression, disease resistance, and plant architecture, underscoring its capacity to complement both conventional and genomics-assisted breeding paradigms (Chandrasekaran *et al.*, 2016). Functional genomics has thus redirected cucumber improvement away from the simple localization of genomic regions toward the mechanistic understanding and experimental validation of the genes underpinning desirable traits forging a direct nexus between genomic discovery and precision breeding.

Genome Editing and Next-Generation Breeding

Genome editing has introduced a level of precision previously unattainable in cucumber breeding, permitting targeted modification of genes underlying agronomically significant traits. Among the platforms currently in use, CRISPR/Cas systems have proven especially valuable for both functional gene validation and direct trait enhancement, with recent investigations demonstrating their applicability to disease resistance, architectural modification, and

manipulation of other complex characteristics. One particularly notable application involves editing of CsaMLO8, a susceptibility gene implicated in powdery mildew infection. CRISPR/Cas9-mediated disruption of this locus yielded cucumber lines exhibiting substantial resistance to *Podosphaera xanthii*, underscoring the utility of targeted loss-of-function mutagenesis for generating disease-resistant germplasm (Shnaider *et al.*, 2023). Comparably, modification of the eIF4E gene has been explored as a strategy for conferring resistance against multiple potyviruses, including watermelon mosaic virus, zucchini yellow mosaic virus, and papaya ringspot virus-W (Ari *et al.*, 2023). Genome editing has furthermore facilitated targeted alteration of genes governing plant architecture, creating opportunities to develop compact plant types better suited to intensive and protected cultivation systems (Jiang *et al.*, 2022).

The convergence of CRISPR-based editing with QTL mapping, GWAS, and functional genomics holds considerable promise for expediting the translation of genomic discoveries into agriculturally deployable alleles. Nonetheless, genotype-dependent transformation efficiency, variable editing precision, off-target effects, and potential pleiotropic consequences continue to pose substantial obstacles to field-level implementation. Even so, the trajectory from candidate-gene identification to direct functional modification marks a decisive advance toward precision breeding in cucumber.

Integration of Conventional and Genomics-Assisted Breeding

Contemporary cucumber improvement rests not on replacing conventional breeding with molecular and genomic tools, but on integrating the two into a unified pipeline. Field-based evaluation continues to play an indispensable role in assessing yield, fruit quality, adaptability, and resistance, while genomic information adds efficiency and precision to the selection process. QTL mapping and GWAS identify genomic regions linked to target traits, which can then be validated and introgressed into elite breeding

material through marker-assisted or genomic selection. This integration of phenotyping, high-throughput genotyping, and genome-wide prediction is especially valuable for complex, multi-locus traits. Genomic selection allows promising individuals to be identified at early developmental stages, reducing the time and resources otherwise required for repeated cycles of phenotypic evaluation (Crossa *et al.*, 2017). Similarly, incorporating genomic data into conventional hybrid breeding programs helps breeders select parents carrying complementary favourable alleles, thereby improving the efficiency of hybrid development.

The emergence of genome editing has further reinforced this integrated approach by providing a direct route from candidate-gene identification to targeted trait modification. As a result, the modern cucumber breeding pipeline increasingly follows a coherent continuum: germplasm evaluation, followed by phenotyping, genomic characterization, gene and QTL discovery, predictive or marker-assisted selection, targeted gene modification, and finally field validation. This integrated framework offers a more efficient and precise pathway for developing cucumber cultivars with enhanced productivity, superior fruit quality, greater stress resilience, and improved adaptation to both protected and intensive production systems.

Challenges and Future Prospects

Despite rapid advances in cucumber genomics, translating genomic discoveries into consistent breeding gains remains challenging. The quantitative inheritance of many agronomic traits, genotype $\times$ environment interactions and the complexity of resistance and quality traits can limit the effectiveness of selection based on individual loci. In addition, the availability of genomic information does not always translate directly into functional validation or effective deployment in elite breeding backgrounds. Future cucumber breeding will therefore depend increasingly on the integration of **high-throughput phenotyping, dense genomic datasets, multi-omics**

and predictive breeding. Pan-genomic resources can broaden the search for favourable alleles beyond the reference genome, while GWAS, genomic selection and transcriptomic analyses can improve the resolution of trait-associated variation. Combining these approaches with genome editing may enable the rapid validation and deployment of favourable alleles and the precise modification of key traits.

Equally important will be the development of cucumber cultivars adapted to changing production environments, including protected cultivation, heat and water limitation, while maintaining yield and fruit quality. The future of cucumber breeding is therefore likely to lie not in replacing conventional approaches, but in integrating **phenotypic selection, molecular breeding and genome-based technologies** into a more precise and efficient breeding pipeline.

Conclusion

Cucumber breeding has undergone a marked transformation, progressing from phenotype-based selection and hybridization toward an increasingly genome-informed discipline. Conventional approaches laid the essential groundwork for advancing yield, fruit quality, sex expression, parthenocarp, and stress adaptation, while the advent of molecular markers and genome sequencing conferred greater precision in identifying and tracking the genetic determinants underlying these traits. The subsequent emergence of GWAS, genomic selection, transcriptomics, and genome editing has further extended breeders' capacity to discover, predict, and directly manipulate favourable genetic variation. The greatest promise for future improvement lies not in treating these approaches as discrete or competing strategies, but in their deliberate integration. Uniting rigorous phenotypic evaluation with genomic information and targeted gene-modification technologies stands to accelerate the development of cucumber cultivars characterized by enhanced productivity, superior fruit quality, greater stress resilience, and improved suitability for modern production systems. The progression from

conventional breeding toward genomics-assisted and precision breeding therefore represents not a repudiation of established breeding principles, but their evolution into a more efficient, integrated, and scientifically informed framework for the future of cucumber improvement.

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AUTHORS' DETAILS:

Ms. V. Lavanya

ICAR CICR Regional Station,
Coimbatore – 641 003

Dr. Isabella Agarwal

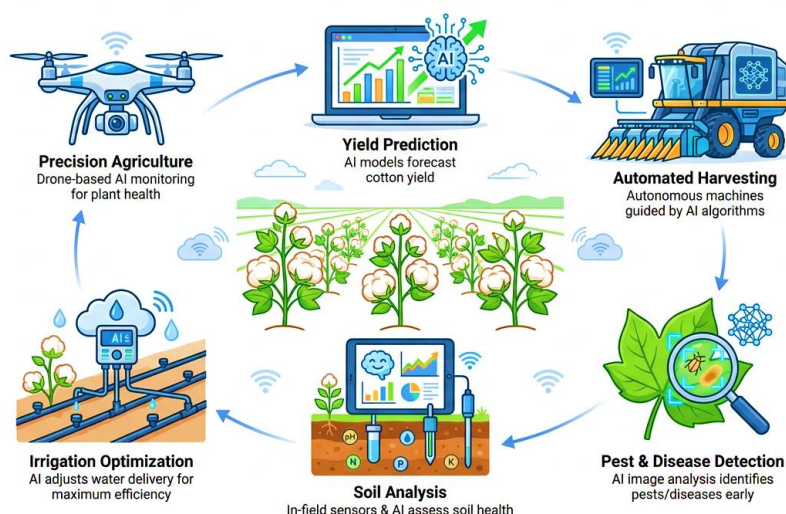
ICAR CICR Regional Station,
Coimbatore – 641 003

ARTICLE ID: 13

Artificial Intelligence in Cotton Farming: From Field Sensing to Precision Decision-Making Process

1. Introduction

Cotton production is increasingly influenced by climate variability, water scarcity, rising input costs, pest and disease pressure, labour constraints and the need for higher productivity with efficient resource use. At the same time, modern cotton fields generate large volumes of information through field observations, weather stations, sensors, satellites, Unmanned Aerial Vehicles (UAVs) and farm machinery. The challenge is to convert this information into timely and practical decisions. Artificial Intelligence (AI), supported by machine learning, computer vision, remote sensing, Internet of Things (IoT) and robotics, provides an opportunity to achieve this transformation. Rather than replacing farmers or agricultural scientists, AI can integrate diverse information and strengthen decision-making at the field level. The emerging concept of smart cotton agriculture therefore combines digital information, precision farming, intelligent mechanization and scientific knowledge to improve productivity, profitability and sustainability.



2. From Traditional Field to Digital Field

The foundation of smart cotton agriculture is reliable field-level information. Variety, sowing date, plant population, irrigation, fertilizer application, pest incidence, plant-protection measures, field operations and yield can be recorded directly through smartphones or digital platforms. Global Positioning System (GPS) coordinates, photographs and time-stamped observations can create a digital history of the cotton crop. When these records are combined across seasons with weather, soil and yield information, they provide valuable datasets for agricultural analysis. Machine-learning algorithms such as Random Forest, Support Vector Machines and Gradient Boosting can identify relationships within these datasets and support prediction and decision-making. Thus, simple field records can become the foundation for a digital cotton production system.

3. Precision Farming: Managing Variability within the Field

Cotton fields are rarely uniform. Soil fertility, moisture, crop vigour and pest incidence can vary considerably within the same field. Precision agriculture uses GPS, GIS, sensors, satellite imagery and UAVs to identify such spatial variability. AI analyses these data to generate management zones and support site-specific decisions. Water, nutrients and crop-protection inputs can consequently be targeted according to field conditions rather than applied uniformly. The transition is therefore from “one field-one management strategy” to “one field-multiple management decisions”.

4. Intelligent Crop Monitoring

AI based computer vision can analyse images acquired through smartphones, UAVs and satellites to monitor cotton growth and identify abnormal crop conditions. Deep-learning models, particularly Convolutional Neural Networks (CNNs), can be trained to recognize visual patterns associated with crop stress, weeds, pest damage and disease symptoms. Multispectral and hyperspectral imagery can provide additional information beyond visible images. The general workflow is:

Image acquisition → Image processing → AI analysis → Detection/classification → Field verification → Management decision



This can enhance the speed, efficiency and spatial coverage of crop monitoring, while field-level validation remains essential for ensuring reliable and accurate assessment.

5. Intelligent Pest and Disease Management

AI can strengthen cotton pest surveillance by combining smart insect traps, field observations,

weather data, crop stage and historical pest records. Computer vision can automatically identify and count insects in image-enabled traps, while machine-learning models can analyse environmental conditions associated with pest development. Such systems can provide early warnings and identify areas requiring closer field inspection. The objective is to move from reactive pest management towards early detection, risk assessment and targeted intervention, thereby supporting more efficient crop protection.

6. Smart Irrigation and Nutrient Management

Cotton water requirements vary with crop stage, soil conditions and weather. IoT based soil moisture sensors, weather stations, evapotranspiration data and remote sensing can provide continuous information on crop water status. AI models can integrate these observations to support dynamic irrigation scheduling. Time-series models such as LSTM networks can be used when sequential weather, soil moisture or crop growth observations are available. Similar approaches can support nutrient management by combining soil test results, crop condition and previous fertilizer applications. The objective is higher productivity per unit of water and nutrient input, rather than simply increasing input use.

7. Intelligent Mechanization for Cotton Production

Mechanization has already transformed several operations in cotton production by reducing dependence on manual labour and improving the timeliness of farm operations. The next stage is intelligent mechanization, in which Artificial Intelligence, robotics, sensors, computer vision, GPS and agricultural machinery work together to make field operations more precise, adaptive and efficient.. AI-enabled mechanization can support cotton production from land preparation to harvesting. GPS-guided tractors can improve field navigation and maintain accurate operating paths, reducing unnecessary overlap during tillage, sowing and other operations. Sensor-based systems can monitor parameters such as soil condition, implement position, crop-row spacing and machine performance. These data can be analysed to improve operational accuracy

and reduce avoidable fuel, time and input use.

a) Precision sowing and crop establishment

Uniform crop establishment is an important factor influencing cotton productivity. Intelligent sowing systems can combine GPS, machine sensors and field information to maintain appropriate row spacing, planting depth and seed placement. AI-based systems can potentially identify variations in soil and field conditions and support variable-rate or site-specific sowing practices. Such technologies are particularly relevant for achieving uniform plant populations and improving the efficiency of subsequent intercultural and harvesting operations.

b) AI-assisted intercultural and weed management

Weed management is another important area for intelligent mechanization. Conventional mechanical operations may treat the entire field uniformly, even when weed distribution is highly variable. Computer vision can be used to distinguish cotton plants from weeds by analysing images captured from cameras mounted on tractors or other field machinery. AI algorithms can then identify weed-infested areas and guide mechanical weeder or targeted spraying systems. This creates a transition from uniform field operation to site-specific operation, where the machine responds to actual field conditions. Such systems can reduce unnecessary passes, minimize input wastage and improve the precision of weed management while protecting the crop.

c) AI-Enabled Precision Crop Protection

The integration of machine vision, sensors and spraying equipment provides opportunities for more precise crop-protection operations. Instead of applying a uniform treatment across an entire field, AI-based systems can identify specific areas requiring attention and support targeted application. Field images, crop-stage information, weather conditions and pest or disease observations can be combined to improve the timing and location of interventions. However, AI-based detection should support rather than replace agronomic verification. The final management decision should consider the severity of the problem,

economic thresholds, weather conditions, crop stage and recommended management practices.

d) AI and cotton harvesting

Cotton harvesting is one of the most important areas for future intelligent mechanization. Harvesting is a time-sensitive operation, and delays can affect yield, fibre quality and production costs. Labour availability and harvesting costs can also influence the economic viability of cotton cultivation. Therefore, the development of efficient and adaptable harvesting technologies is particularly important. Modern harvesting systems can integrate machine vision, sensors, automated navigation and robotic technologies to identify crop rows, locate cotton bolls and guide harvesting mechanisms. Vision systems can provide information on boll distribution, crop structure and field conditions, while automated navigation can help machinery maintain accurate movement through cotton rows.. Such technologies could contribute to improved picking efficiency, reduced crop losses, better timeliness and more consistent harvesting performance.

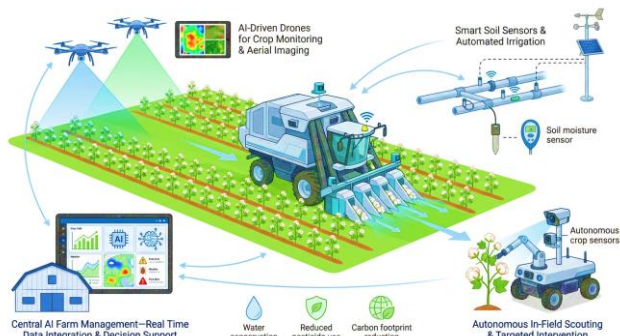
e) From mechanization to intelligent mechanization

The development of cotton mechanization can therefore be viewed as a progression:

Manual operation → Mechanization → Precision mechanization → Intelligent mechanization

In conventional mechanization, the machine performs a predefined operation. In precision mechanization, technologies such as GPS and sensors improve the accuracy of that operation. In intelligent mechanization, AI and machine vision enable the system to sense, interpret and respond to changing field conditions. The future cotton production system is therefore likely to involve machines that not only perform agricultural operations but also function as mobile sensing and decision-support platforms. A tractor, planter, sprayer or harvester can simultaneously collect field data while carrying out its primary operation. These data can subsequently be integrated with weather information, satellite imagery, soil data and farm records to improve subsequent

decisions. The ultimate objective of intelligent mechanization is therefore not merely to replace human labour, but to improve the timeliness, precision, operational efficiency, input-use efficiency, safety and overall performance of cotton production.



8. AI for Higher Cotton Productivity and Resource-Use Efficiency

Beyond prediction and monitoring, AI can also contribute to optimization of cotton production under multiple and often competing objectives. Approaches such as Fuzzy Goal Programming (FGP) can help identify feasible production strategies by considering different goals and constraints simultaneously, such as maximizing cotton productivity and returns while reducing resource use and production costs. This establishes a practical connection between AI-driven insights and resource optimization, enabling informed decision-making under uncertainty, resource constraints and multiple competing production objectives. Thus, future productivity enhancement can increasingly move beyond simply applying more inputs towards optimizing how, when and where available resources are used. The integration of AI, predictive analytics and optimization approaches can support cotton production systems that are more productive, resource-efficient, economically viable and resilient.

9. Challenges and Future Directions

AI adoption in cotton agriculture faces several challenges, including data quality, model reliability, field-level validation, affordability, connectivity, interoperability, digital literacy and data governance.

AI models developed under one agro-climatic condition may not perform equally well under another. Therefore, locally representative datasets and multi-season, multi-location validation are essential. Future AI systems should be scientifically robust, affordable, farmer-centric, locally validated and easy to interpret. Collaboration among farmers, agricultural scientists, engineers, data scientists and technology developers will be essential for translating AI research into practical cotton solutions.

10. Conclusion

Artificial Intelligence is creating new possibilities for cotton agriculture by connecting field observations, digital records, sensors, remote sensing, precision technologies and mechanization. Its greatest value lies not in replacing human knowledge, but in strengthening the ability to observe crop conditions, identify variability, predict emerging risks and support timely decisions. The cotton production system of the future is likely to be increasingly digital, precise, mechanized and predictive. The integration of AI with IoT, remote sensing, robotics, weather intelligence and agronomic expertise can contribute to higher productivity, improved resource-use efficiency and greater resilience. The journey towards smart cotton agriculture can therefore be summarized as a transition from data collection to data intelligence, from mechanization to intelligent mechanization, and from reactive management to predictive decision-making. The future of cotton production will depend not simply on generating more data or deploying more technologies, but on transforming information into timely, precise and actionable decisions. Ultimately, AI can transform cotton agriculture by enabling farmers and scientists to detect earlier, understand deeper, decide smarter and act more precisely, creating a more productive, efficient, resilient and sustainable future for cotton production.

AUTHORS' DETAILS:

Chavan Nikita Vijay

Department of Entomology,
Post Graduate Institute,
Mahatma Phule Krishi
Vidyapeeth, Rahuri,
Maharashtra, India

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PESTICIDE RESIDUES: A GROWING CONCERN FOR FOOD SAFETY

Introduction

Pesticides are an important tool in modern agriculture for managing insects, weeds and diseases and for minimizing crop losses and maintaining productivity. India is among the major pesticide-consuming countries in the world and is also a leading pesticide manufacturer in Asia. However, the extensive and sometimes indiscriminate use of pesticides has raised concerns regarding their persistence in the environment, effects on non-target organisms and contamination of agricultural produce. Fruits and vegetables form an essential part of the human diet and are consumed regularly, with many vegetables and fruits being eaten fresh or with minimal processing. Consequently, the presence of pesticide residues in these commodities has attracted considerable attention from the perspective of food safety. Pesticide residues are the small amounts of pesticides or their metabolites that may remain in food following their use in crop production. When residues occur at levels above the prescribed Maximum Residue Limits (MRLs), they indicate improper or excessive pesticide use and may require further assessment of consumer exposure and dietary risk. Therefore, monitoring pesticide residues in food commodities is essential for assessing food safety, ensuring compliance with established standards and promoting the judicious use of pesticides.

➤ What are pesticide residues and MRL?

A pesticide residue is any specified substance in food, agricultural commodities, or animal feed resulting from the use of a pesticide. The term includes any derivatives of a pesticide, such as conversion products, metabolites, reaction products, and impurities considered to be of toxicological significance. (FAO)

A **Maximum Residue Limit (MRL)** is the highest legal concentration of a pesticide residue allowed in or on food or animal feed, expressed in milligrams per kilogram (mg/kg).

➤ Major reasons for the occurrence of high pesticide residues in India

- Farmers are frequently using non-recommended insecticides
- Application of pesticides higher dose than recommended one
- Non-observance of the prescribed waiting period
- Use of poor-quality or sub-standard pesticides
- Wrong disposal of leftover and cleaning of plant protection equipment
- Application of pesticides shortly before harvest
- Lack of awareness regarding appropriate pesticide selection, dose and application practices

➤ Impact of pesticide residues

1) Impact on human health

Continuous exposure to certain pesticide residues through contaminated food may be associated with adverse health effects. The nature and severity of effects depend on the pesticide, level and duration of exposure, and individual susceptibility. Some pesticides are known to affect the nervous, endocrine, reproductive or other physiological systems at sufficiently high or prolonged exposure. Therefore, assessing dietary exposure is important in determining whether detected residues represent a potential health concern.

2) Impact on the environment

Pesticide residues do not always remain confined to the target crop. They may reach **soil, water and air** through spray drift, runoff and leaching. Persistent residues can affect non-target organisms such as beneficial insects, pollinators, earthworms, aquatic organisms and microorganisms, potentially disturbing ecological processes and food webs.

3) Impact on food safety

The presence of pesticide residues in food has become an important food-safety concern. Residues detected above the established **Maximum Residue Limits (MRLs)** may indicate inappropriate pesticide application or failure to follow the recommended pre-harvest interval and can result in **regulatory action, including rejection or withdrawal of commodities that do not comply with prescribed residue standards.**

4) Impact on agriculture

Repeated and improper use of pesticides can contribute to **pest resistance**, resurgence of pests and disruption of natural enemies. This may gradually reduce the effectiveness of certain pesticides and increase farmers' dependence on chemical control.

➤ How Can Pesticide Residues Be Reduced?

At the farm level

- Follow the **recommended pesticide, dose and method of application.**
- Avoid unnecessary or repeated pesticide applications.

- Follow the prescribed **pre-harvest interval (PHI)** between the last pesticide application and harvesting given by CIB& RC
- Adopt **Integrated Pest Management (IPM)** and use non-chemical methods wherever practical.
- Avoid using pesticides that are not recommended for a particular crop or pest.
- Maintain proper records of pesticide applications to support traceability and safe production.
- Use properly calibrated spraying equipment to minimize excessive application and spray drift.

At the consumer level

- Wash fruits and vegetables thoroughly under clean running water before consumption to remove dirt and some surface pesticide residues.
- Household decontamination methods such as washing with salt water, tamarind water or lemon water may help reduce certain pesticide residues from the surface of fruits and vegetables.
- Peeling and trimming can further reduce residues present mainly on the outer surface.
- Cooking, blanching and suitable hot-water treatments may reduce certain pesticide residues, depending on the pesticide and commodity.

➤ Regulation and Monitoring of Pesticide Residues

Regulatory Authorities in India

FSSAI (Food Safety and Standards Authority of India): Operates under the Ministry of Health and Family Welfare; fixes safety standards and MRLs for pesticide residues in food items.

CIB&RC (Central Insecticides Board and Registration Committee): Registers pesticides and evaluates their safety and toxicity before they are approved for use in agriculture.

Department of Agriculture & Farmers Welfare:

Implements the Monitoring of Pesticide Residues at National Level (MPRNL) scheme using NABL-accredited labs to test market and farm-gate food samples.

International Regulatory Authorities

Codex Alimentarius Commission (FAO/WHO)

EFSA (European Food Safety Authority)

USFDA / EPA (Environmental Protection Agency)

➤ **Analytical Techniques for Pesticide residue extraction**

Modern pesticide residue analysis commonly uses the Quick, Easy, Cheap, Effective, Rugged, and Safe (QuEChERS) method and it was developed in 2003 by [Michelangelo Anastassiades](#) and colleagues. It is an efficient and convenient extraction technique for the analysis of pesticides and other contaminants in agricultural products using acetonitrile extraction and dispersive solid-phase extraction cleanup.

This **QuEChERS extraction method coupled with GC-MS/MS or LC-MS/MS**, as this combination provides rapid, sensitive, and reliable detection of hundreds of pesticide residues in a wide variety of food and environmental samples.

➤ **Conclusion**

Ensuring food safety requires a concerted effort to minimize pesticide residues while maintaining effective crop protection. Greater awareness and adoption of **Integrated Pest Management (IPM)** practices can help farmers reduce unnecessary dependence on chemical pesticides and thereby minimize residue contamination in vegetables. Regular monitoring of pesticide residues, strict adherence to recommended pesticide doses and pre-harvest intervals, effective regulatory measures, and proper residue testing are equally important. A coordinated approach involving **farmers, scientists, regulatory agencies, residue-testing laboratories, and consumers** can strengthen the food-safety system and contribute to the production of safer, healthier and more sustainable food for all.

AUTHORS' DETAILS:**Ayushi Pal¹****Hashim Zahoor²****Shivani Jha³**

¹Assistant Professor,
Department of Agricultural
Economics and Extension, Lovely
Professional University,
Phagwara-144411, Punjab, India

²Assistant Professor,
Department of Computer
Applications, Lovely Professional
University, Phagwara-144411,
Punjab, India

³Young Professional,
National Research Centre for
Makhana, Darbhanga-846005,
Bihar, India

ARTICLE ID: 15**The Changing Landscape of Agricultural Communication****Abstract**

Agricultural communication has changed rapidly in the 21st century; from one-way dissemination of farm information to interactive, participatory and digitally connected systems. Today, farmers receive information through extension workers, mobile phones, social media, peer networks, markets and digital advisory platforms. The central challenge is therefore not simply access to information, but understanding, verifying and applying it in a particular farming context. This article traces the evolution of agricultural communication and examines the role of digital technologies, participation, trust, inclusion and emerging tools such as artificial intelligence. It argues that effective communication must combine technological reach with local knowledge, human interaction, credible information and opportunities for farmer feedback.

1. Introduction

Communication, at its core, is not simply about transmitting information; it is about how meaning is shaped, interpreted, and understood within a given context. In contemporary agricultural communication, this distinction is increasingly important because farmers encounter information through extension personnel, mobile phones, social media, peer networks, markets, and digital advisory systems. Communication effectiveness therefore depends not only on the accuracy of a message but also on its relevance, credibility, accessibility, and fit with local experience.

Information flows continuously through mobile devices, digital platforms, and peer networks. Yet, paradoxically, the challenge is no longer simply access to information but making sense of it. Farmers may encounter several recommendations on the same crop, pest, weather event, or market decision, sometimes with conflicting claims. The communication task has therefore expanded from information delivery to interpretation, verification, and application. A message about crop management is meaningful only when it aligns with farmers' experience, resources, language, and production environment. The changing landscape of agricultural communication in the 21st century therefore reflects a broader transformation: from linear dissemination to interactive, context-driven, participatory, and digitally mediated systems. The central question is no longer only how information reaches farmers, but how communication helps farmers understand, evaluate, and use that information.

2. Rethinking Agricultural Communication

To understand this transformation, it is useful to move beyond functional definitions of communication and consider theoretical perspectives that explain adoption, participation, and audience choice. Diffusion of Innovations explains how innovations spread through communication channels over time, while contemporary agricultural scholarship shows that digitalisation also changes skills, power relations, knowledge systems, and institutional arrangements. However, diffusion theory alone is insufficient to explain contemporary communication dynamics. Participatory communication shifts the focus from transmission to dialogue, feedback, and co-creation of knowledge. Farmers are not merely recipients of recommendations; they also contribute experiential knowledge and help adapt innovations to local conditions. Similarly, Uses and Gratifications theory emphasises that audiences actively select media and information according to their needs and expected benefits. In agriculture, this helps explain why farmers may prefer different channels—such as local-language videos, messaging groups, peer recommendations or direct contact with extension personnel—depending on the type and urgency of information required.

3. Evolution of Agricultural Communication

Agricultural communication has evolved through distinct but overlapping phases. The early linear phase was characterised by one-way dissemination, where knowledge moved from research institutions to farmers through extension agents. Later phases introduced feedback and participation, while the current digital ecosystem connects farmers, extension personnel, researchers, markets, devices, and platforms through continuous and multi-directional information flows.

- The linear phase (mid-20th century) was characterised by one-way dissemination. Knowledge moved from research institutions to farmers through extension agents. This model proved effective under conditions where innovations were standardised and contexts relatively uniform.
- The interactive phase introduced feedback mechanisms. Farmers could respond,

question, and adapt recommendations, though the system remained largely hierarchical.

- The participatory phase marked a deeper shift. Communication became dialogic, and knowledge began to emerge through interaction. Farmers' experiential knowledge gained recognition.
- The current digital ecosystem phase integrates ICTs, mobile platforms, and data analytics into communication processes. Information flows are now multi-directional and continuous.

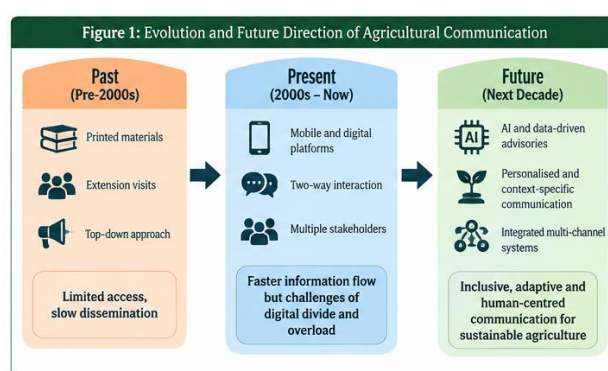


Figure 1. Evolution of agricultural communication from linear dissemination to interactive, participatory and digital ecosystem-based communication.

Source: Conceptual synthesis based on the communication phases discussed in this article.

Communication as Experience: The Human Dimension

Studies have consistently shown that farmers are more likely to adopt innovations when communication is contextual, relatable, and delivered in familiar language. These factors are not incidental; they shape how messages are interpreted and whether they are trusted. Communication, therefore, becomes less about accuracy alone and more about relevance. One of the most significant yet often overlooked aspects of agricultural communication is its human dimension. Communication is not simply about content; it is about relationships, trust, and interpretation. Studies have shown that farmers are more likely to adopt innovations when communication is:

- Contextual

- Relatable
- Delivered in familiar language

This aligns with the concept of frames of reference, which suggests that individuals interpret messages based on their prior experiences and cultural context. When communication fails to align with these frames, it often leads to misunderstanding or rejection. For instance, a technically accurate message about climate-smart agriculture may fail if it does not resonate with local practices. This highlights the importance of empathetic communication, where the communicator not only transmits information but also understands the audience.

5. Drivers of Change in the 21st Century

Digital Transformation

The integration of digital technologies has fundamentally reshaped agricultural communication. Mobile phones, digital platforms, sensors, Internet of Things systems, data analytics, and artificial intelligence can make information more timely and more specific to farm conditions. Smart-farming systems increasingly connect field observations with decision-support tools, although technology alone does not guarantee meaningful or equitable use.

India's digital audience has expanded substantially, and the rural component is especially important for agricultural communication. IAMAI–Kantar reported 886 million internet users in India in 2024, including 488 million rural users and 397 million urban users. These are general internet-use estimates rather than farmer-specific measures, but they provide useful context for the growing potential audience for digitally mediated agricultural communication.

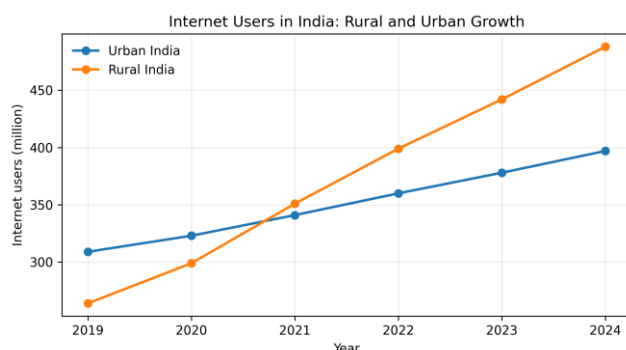


Figure 2. Internet users in India by rural and urban location, 2019–2024 (million).

Source: IAMAI–Kantar, *Internet in India 2024*.

Digital Divide and Inclusion

Despite rapid technological advancements, digital inequality remains a central concern. Access to devices and connectivity is only one part of inclusion; digital skills, affordability, language, gender, trust, and the ability to evaluate information also shape effective use. Global evidence continues to show substantial digital-access and skills gaps, while FAO identifies connectivity, digital literacy, infrastructure, and financial constraints as barriers to inclusive digital agricultural transformation.

Climate Uncertainty and Risk Communication

Climate variability has increased the demand for timely and reliable risk communication. Weather information, early warnings, and locally appropriate adaptation advice can support farm-level decision-making, but the value of such information depends on farmers' ability to access, interpret, and act upon it.

Market Integration

Agricultural communication increasingly includes market intelligence. Farmers must interpret price signals, demand trends, quality requirements, and changing value-chain conditions. Digital platforms can widen access to market information, but communication systems must also account for unequal connectivity, digital skills, and the credibility of information sources.

Institutional and Policy Shifts

Policy and institutional arrangements increasingly position communication as a strategic component of agricultural development. Contemporary agricultural knowledge systems involve public extension, research institutions, private actors, farmer organisations, digital platforms, and community networks. The result is a more distributed communication environment in which no single institution controls the entire information flow.

A growing body of literature also highlights systemic constraints that shape the effectiveness of ICT-based communication. Digital tools can improve speed and reach, but meaningful impact depends on trust, accessibility, prior experience, digital capability, institutional support, and the quality of the underlying data.

Social Media, Information Overload and Trust

Digital agricultural communication increasingly operates through messaging services, video platforms, social media, online communities, and peer networks. These channels can make agricultural information faster and more accessible, but they also increase the volume of competing messages. The communication challenge therefore includes verification: farmers need cues that help them distinguish evidence-based advice from unsupported claims. Source credibility, transparent attribution, local-language communication, and links with trusted extension and research institutions become increasingly important.

Gender, Inclusion and Responsible AI

The future of agricultural communication also requires attention to who is included and who is left out. Gender, age, literacy, language, income, disability, and access to devices can influence the ability to benefit from digital advisory services. Communication strategies should therefore combine local-language and voice-based content, accessible interfaces, capacity building, and opportunities for two-way feedback. Artificial intelligence can support personalised advisories, crop monitoring, weather interpretation, and decision support, but its usefulness depends on data quality, connectivity, transparency, privacy, and human oversight. AI should complement—not eliminate—the role of extension professionals and locally embedded knowledge systems.

6. Conclusion

The transformation of agricultural communication in the 21st century is not simply a technological shift; it is a conceptual one. Agricultural communication is moving from one-way information delivery towards interaction, participation, contextual interpretation, and digitally connected knowledge systems. The next stage should not be defined by technology alone. Effective communication will depend on combining digital reach with human trust, local knowledge, inclusive design, credible information, and meaningful feedback. In practice, this means using multiple channels rather than replacing traditional extension, communicating in locally appropriate language, strengthening farmers' digital and information literacy, and ensuring that AI and data-driven tools remain transparent and accountable. The ultimate objective is not to make information circulate faster, but to ensure that useful knowledge becomes understandable, trusted, and actionable in real farming contexts.

AUTHORS' DETAILS:

H. Nagesh,

V. Jyothi,

K. Srinivasarao,

V. Ramarao

*Sri Kinjarapu Yerrannaidu
College of Agriculture-
ANGRAU, AP-532401.*

ARTICLE ID: 16

Digital Agricultural Extension: Transforming Farmer Advisory Services in the Digital Era

Introduction

Agriculture is rapidly changing with the advancement of digital technologies. Farmers today require not only inputs such as seed, fertilizer and machinery, but also timely and reliable information to make better decisions. Weather variability, emerging pests and diseases, changing market prices, water scarcity and increasing production costs have made timely agricultural advisories more important than ever. In this changing scenario, **digital agricultural extension** is emerging as a powerful approach for connecting farmers with knowledge, experts, markets and services.

Traditional agricultural extension has mainly depended on personal visits, demonstrations, farmer meetings, training programmes, field days and printed materials. These approaches continue to be important, particularly for hands-on learning. However, they may not always reach every farmer at the right time. Digital technologies can complement conventional extension by delivering information quickly, widely and in a farmer-friendly manner.

What is Digital Agricultural Extension?

Digital agricultural extension refers to the use of information and communication technologies (ICTs), mobile phones, internet-based platforms, social media, artificial intelligence, digital applications, satellite technologies and other digital tools to provide agricultural knowledge and advisory services to farmers.

It enables farmers to access information without always having to physically visit an extension office. A farmer can receive a weather alert on a mobile phone, watch a video on a crop management practice, identify a pest through a digital application, check market prices online or communicate with an agricultural expert through a digital platform.

Thus, digital extension is not simply the replacement of traditional extension with technology. It represents a transition towards a more accessible, timely, interactive and farmer-centred extension system.

Digital Tools Transforming Agricultural Extension

Several digital technologies are changing the way agricultural information is generated, communicated and used.

1. Mobile Phones

Mobile phones have become one of the most important tools for agricultural extension. SMS messages, voice calls, mobile applications and messaging platforms can provide farmers with information on crop production, weather, pest management, government schemes and market opportunities.

Voice-based services are particularly useful for farmers who have limited literacy or prefer receiving information in their local language.

2. Social Media

Social media platforms have created new opportunities for farmer learning and interaction. Agricultural departments, universities, Krishi Vigyan Kendras, experts and farmer groups can share crop advisories, demonstration videos, success stories and alerts through social media.

Farmer-to-farmer communication can also become faster through digital communities.

3. Digital Videos

Agriculture is a practical field, and many farming operations are easier to understand through visual demonstrations. Digital videos can demonstrate seed treatment, nursery management, mechanization, integrated pest management, compost preparation, harvesting and post-harvest practices.

Local-language videos can make technical information easier for farmers to understand and apply.

4. Weather and Climate Advisory Services

Weather information is becoming increasingly important for farm-level decision-making. Digital platforms can provide information about rainfall, temperature, wind, dry spells and extreme weather events.

Such advisories can help farmers decide when to sow, irrigate, spray pesticides, apply fertilizers or harvest crops. Climate-related advisories can also support farmers in preparing for droughts, floods, heat waves and other risks.

5. Artificial Intelligence

Artificial Intelligence (AI) is creating new possibilities for agricultural advisory services. AI-based systems can analyse large amounts of agricultural, weather and market information and provide customized recommendations.

For example, AI-based applications may assist in identifying crop diseases from photographs, recommending suitable management practices or answering farmers' frequently asked questions through chatbots.

However, AI should complement—not replace—qualified agricultural experts and field-level extension personnel.

6. Remote Sensing, GIS and Drones

Satellite imagery, Geographic Information Systems (GIS) and drone technologies can provide valuable information about crop conditions, soil moisture, vegetation health, pest outbreaks and drought conditions.

These technologies can help extension agencies identify vulnerable areas and provide targeted advisories rather than applying the same recommendation to all farmers.

How Digital Extension Benefits Farmers

Digital agricultural extension can provide several benefits to farmers.

Timely information: Agricultural advisories can reach farmers quickly, particularly during critical crop-management periods.

Wider coverage: A single digital message, video or advisory can reach thousands of farmers across geographically dispersed areas.

Lower cost: Digital communication can reduce the cost associated with repeated physical meetings and travel.

Personalized advice: Digital systems can increasingly provide recommendations based on crop, location, weather and farmer needs.

Better decision-making: Access to weather, market, pest and production information can help farmers make informed decisions.

Continuous learning: Farmers can access agricultural information whenever required instead of depending only on scheduled extension programmes.

Improved connectivity: Digital platforms can connect farmers with scientists, extension officers, markets, financial institutions and other service providers.

Digital Extension and Climate-Resilient Agriculture

Digital agricultural extension has particular importance in the context of climate change. Rainfed farmers frequently face uncertainties associated with delayed monsoon, prolonged dry spells, excessive rainfall, high temperatures and changing pest and disease patterns.

Digital climate advisories can help farmers prepare for these risks. For example, farmers can

receive early warnings about heavy rainfall and modify irrigation, fertilizer application or harvesting decisions accordingly. Short-duration crop varieties, contingency crop planning and drought-management practices can also be communicated through digital platforms.

Therefore, digital extension can become an important component of climate-risk management and resilient agricultural development.

Role of Extension Personnel in the Digital Era

The emergence of digital technology does not reduce the importance of extension personnel. Instead, their role is changing. The extension worker of the future needs to function as a knowledge facilitator, digital communicator, technology mediator and problem-solving expert. Extension personnel should be able to identify credible information, communicate it through appropriate digital channels and help farmers interpret and apply it under local conditions.

A strong extension system should therefore combine digital tools with personal interaction. Digital platforms can provide speed and scale, while extension personnel provide local understanding, practical guidance, trust and human interaction.

Challenges of Digital Agricultural Extension

Despite its potential, digital extension faces several challenges.

The **digital divide** remains an important concern. Small and marginal farmers, women farmers, elderly farmers and farmers in remote areas may have limited access to smartphones, internet connectivity or digital services.

Digital literacy is another challenge. Having a smartphone does not necessarily mean that a farmer can effectively search for, evaluate and use agricultural information.

Information overload can also create confusion. Farmers may receive contradictory recommendations from different sources. Therefore, the credibility and quality of digital agricultural information are extremely important.

Language is another major issue. Digital agricultural content should be available in local and easily understandable languages rather than relying mainly on technical terminology.

Poor internet connectivity, limited electricity supply, affordability of devices and concerns regarding data privacy are additional barriers.

Making Digital Extension More Farmer-Centred

The success of digital agricultural extension depends not simply on introducing new technologies but on designing services around farmers' actual needs.

Digital advisory systems should provide:

- Local-language information
- Simple and practical recommendations
- Location-specific advisories
- Weather-based recommendations
- Crop-specific information
- Audio and video content
- Interactive farmer–expert communication
- Reliable and scientifically validated information
- Accessible services for women and marginalized farmers

Farmers should also be involved in designing and evaluating digital extension services. Their feedback can help improve the relevance, usability and credibility of digital platforms.

The Future of Agricultural Extension

The future of agricultural extension is likely to be hybrid, combining the strengths of traditional and digital approaches. Digital technologies can provide information rapidly and reach large numbers of farmers, while face-to-face extension can provide practical demonstrations, build trust and address complex field-level problems.

The integration of Artificial Intelligence, Internet-based services, remote sensing, mobile applications, climate information and farmer databases may enable more personalized and predictive agricultural advisory systems in the future. However, technology should remain a means rather than an end. The ultimate objective of digital extension should be to improve farmers' knowledge, decision-making capacity, productivity, income and resilience.

Conclusion:

Digital agricultural extension is transforming the way agricultural knowledge and advisory services reach farmers. Mobile phones, social media, digital videos, weather services, artificial intelligence, remote

sensing and other technologies are creating new opportunities for faster and more accessible agricultural communication.

At the same time, technology alone cannot solve all agricultural problems. Bridging the digital divide, improving digital literacy, ensuring reliable information, promoting local-language content and strengthening the capacity of extension personnel are essential.

The future of agricultural extension lies in creating a farmer-centred, inclusive and technology-enabled extension ecosystem in which digital tools and human expertise work together. If used effectively, digital agricultural extension can help farmers make better decisions, respond to emerging challenges and move towards a more productive, sustainable and climate-resilient agriculture.

AUTHORS' DETAILS:

Dr. Shelke P. P.

Senior Scientist and Head,
Krishi Vigyan Kendra,
Hingoli. 431701 (M.S.)

Dr. Murai Atul. M.

Subject Matter Specialist
(Agricultural Extension),
Krishi Vigyan Kendra,
Hingoli. 431701 (M.S.)

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TRANSFORMATION FROM TRADITIONAL CROPPING TO INTEGRATED HORTICULTURE MANAGEMENT

A Detailed Success Story of Shri. Babanrao Vitthalrao Dhoble

INTRODUCTION

The Hingoli district, located in the Marathawada region of Maharashtra State, is characterized by **rainfed agriculture, erratic monsoon patterns, and limited irrigation facilities**. A majority of farmers in this region depend on traditional cropping systems such as turmeric, soybean, pigeon pea, and cotton. While these crops are well-suited to local conditions, they often fail to provide **stable and sufficient income** due to climatic uncertainties, increasing input costs, pest and disease incidence and fluctuating market prices. In such a challenging agricultural scenario, there is a growing need for **diversification and adoption of sustainable farming systems** that can ensure better income, resource use efficiency, and resilience to climate variability. Integrated horticulture management has emerged as a promising approach in dry land areas offering **year-round income, efficient water utilization and long-term sustainability**. Against this backdrop, success story of Shri. Babanrao Vitthalrao Dhoble, a progressive farmer from Asola Tarfe Aundha village in Aundha Nagnath, stands out as an inspiring example of agricultural transformation. By shifting from traditional mono-cropping to a **well-planned integrated horticulture system** with technical guidance from Krishi Vigyan Kendra, Hingoli he successfully converted a low-income, risk-prone farming system into a **profitable, sustainable, and climate-resilient enterprise**. This success story not only highlights the importance of **scientific interventions, capacity building and institutional support** but also serves as a **replicable model for dry land farmers** of Hingoli district.

BACKGROUND OF THE FARMER AND FARMING SITUATION

Shri. Babanrao Vitthalrao Dhoble, a resident of Asola Tarfe Aundha village in Aundha Nagnath, owned 4 acres of dry land. Initially, his farming system consisted of Soybean (Kharif), Pigeon pea & Cotton. These crops were entirely dependent on monsoon rainfall.

MAJOR CONSTRAINTS FACED:

1. Climatic Constraints

- Erratic onset and withdrawal of monsoon
- Long dry spells during crop growth stages
- Occasional drought conditions

2. Soil-Related Issues

- Low organic carbon content
- Poor moisture retention capacity
- Imbalanced nutrient status

3. Economic Constraints

- High input costs
- Low productivity due to moisture stress
- Price volatility in markets

4. Biotic Stress

- Pest outbreaks
- Disease incidence in soybean and tur

Due to these challenges, his annual net income remained between ₹1.2 to 1.5 lakh, which was insufficient for sustaining the household and reinvestment in farming.

ROLE OF INSTITUTIONAL SUPPORT AND CAPACITY BUILDING

The turning point came when Shri. Babanrao Vitthalrao Dhoble established contact with Krishi Vigyan Kendra, Hingoli.

Key Interventions by KVK:

- On-field technical guidance
- Exposure visits to successful orchards
- Training on horticulture and water management
- Demonstrations on drip irrigation and INM/IPM practices
- Weather forecasting message

Capacity Building Activities:

- Training on fruit crop cultivation
- Hands-on exposure to modern irrigation systems
- Skill development in pest and nutrient management
- Continuous advisory support

These efforts enhanced his confidence and decision-making ability.

PLANNING AND IMPLEMENTATION OF INTEGRATED HORTICULTURE MODEL

4.1 Land Use Planning

A systematic plan was developed considering

- Soil type and slope
- Water availability
- Crop compatibility
- Market demand

The 4-acre land was divided for efficient layout of fruit crops with proper spacing.

4.2 Crop Diversification Strategy

Instead of mono-cropping, a multi-tier horticulture system was adopted.

Crop	Nature	Purpose
Papaya	Short duration	Early income (within 2 year)
Guava	Medium duration	Stable returns (2-3 years)
Coconut	Long duration	Long-term security
Sugarcane	Annually Crop	Stable returns

This ensured income at different time intervals, reducing financial risk.

TECHNOLOGIES AND PRACTICES ADOPTED

5.1 Scientific Orchard Establishment

- Proper pit size
- Filling pits with FYM, soil, and micronutrients
- Recommended spacing for each crop
- Windbreak and boundary plantation

5.2 Water Management through Drip Irrigation

Drip irrigation was a crucial intervention:

- Daily controlled water supply directly to root zone
- Reduced evaporation losses
- Efficient fertigation

Benefits Achieved:

- 40–50% water saving
- Improved plant growth
- Reduced weed infestation
- Higher water use efficiency

5.3 Integrated Nutrient Management (INM)

A balanced approach combining organic and inorganic sources:

- Application of FYM (10-15 tons/ha)
- Use of bio fertilizers
- Split application of NPK fertilizers
- Foliar spray of micronutrients

Outcome:

- Improved soil fertility
- Better nutrient uptake
- Enhanced yield and quality

5.4 Integrated Pest and Disease Management (IPDM)

Eco-friendly and scientific pest control:

- Installation of pheromone traps
- Use of neem-based bio pesticides

- Biological agents like Trichoderma
- Need-based chemical application

Outcome:

- Reduced pesticide cost
- Lower environmental impact
- Effective pest control

5.5 Mulching and Moisture Conservation

- Use of organic and plastic mulch
- Reduced evaporation
- Maintained soil temperature
- Improved microbial activity

5.6 Intercropping System

During initial years, intercrops were taken:

- Vegetables
- Provided additional income
- Improved soil fertility

ECONOMIC IMPACT AND FINANCIAL ANALYSIS

Before Intervention

- Net Income: ₹1.2–1.5 lakh/year
- High risk due to seasonal dependency

After Intervention

- Net Income: ₹4.5–5.5 lakh/year

Key Economic Advantages

- Regular income flow
- Reduced dependency on a single crop
- Better market opportunities

Papaya started yielding within the second year, providing immediate returns. Guava stabilized income within 2-3 years while coconut ensured long-term profitability.

SOCIAL AND LIVELIHOOD IMPACT

Employment Generation

- 80-100 labour required for farm operations yearly.
- Activities: pruning, harvesting, grading, irrigation management

Family Benefits

- Increased family involvement in farming
- Reduced migration to urban areas
- Improved standard of living

HORIZONTAL SPREAD AND EXTENSION IMPACT

The success of Shri. Babanrao Dhoble inspired nearby farmers:

- 20-30 farmers adopted fruit-based systems
- Increased awareness about horticulture
- His farm became a live demonstration unit

KVK used his field for:

- Farmer field days
- Training programs
- Technology demonstrations

This significantly contributed to technology dissemination in the region.

SUSTAINABILITY AND ENVIRONMENTAL BENEFITS

- Efficient water utilization
- Improved soil health
- Reduced chemical load
- Climate-resilient farming system

The system proved sustainable under dry land conditions.

KEY LESSONS LEARNED

- Diversification reduces risk in dry land farming
- Scientific water management is crucial
- Integrated nutrient and pest management improves sustainability
- Institutional support plays a vital role
- Multi-tier horticulture ensures continuous income



Shri. Babanrao Dhoble awarded as Vasantrya Naik Shetinisht Shetkari Puraskar 2023 of Maharashtra State



**आमची माती
आमची मानस**

विषय
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 मु.पो.आसोला तर्फे औंढा, ता.औंढा नागनाथ, जि.हिंगोली

डॉ.अतुल मुराई
 विषय विशेषज्ञ (कृषी विस्तार)
 कृषी विज्ञान केंद्र, तोंडापूर, ता. कळमनुरी, जि. हिंगोली

सूत्रसंचालन - औंकार चिटणीस
 लेखन - दिनानाथ परब निवेदन - सुषमा जाधव

प्रसारण
 मंगळवार दि. १०.२.२०२६ सायंकाळी ६.३० वा.

Success story broadcast on D.D. Sahyadri
 10/02/2026 on Aamchi Maati Aamchi Manas
 Programme

CONCLUSION

The story of Shri Babanrao Vitthalrao Dhoble is ultimately a story of transformation. A four-acre dry land farm that once depended heavily on uncertain monsoon rainfall and conventional seasonal crops was transformed into a diversified horticulture-based enterprise. With guidance from Krishi Vigyan Kendra, Hingoli the farmer adopted papaya, guava and coconut along with drip irrigation, integrated nutrient management, integrated pest and disease management, mulching, moisture conservation and intercropping. His farm has shown that when scientific knowledge, farmer initiative and institutional support come together, even a small landholding can become a productive and resilient enterprise. From traditional cropping to integrated horticulture, from seasonal uncertainty to diversified income, and from an individual farm to a community demonstration- Shri Babanrao Dhoble's journey represents the power of scientific agriculture to transform not only a farm, but the future of farming itself.

His journey can be summed up in one message,

“Do not measure the potential of a farm only by its size. Measure it by how wisely its soil, water, crops, technology and opportunities are managed.”

AUTHORS' DETAILS:

Chitte Karishma

Professor
Jayashankar Telangana
Agricultural University,
Hyderabad

ARTICLE ID: 18

ARTIFICIAL RECHARGE FOR GROUNDWATER AUGMENTATION

Introduction:

In regions such as India, California, and the Middle East, excessive groundwater extraction and reduced natural replenishment due to urbanization and climate change have led to aquifer depletion, making recharge efforts essential for avoiding scarcity, securing food supply, and preserving dependent ecosystems.

In India, where over 60% of irrigation relies on groundwater, declining water tables put extra pressure on farmers and utilities to pump water, and effective recharge is essential to prevent land subsidence and support vital ecosystems.

Natural recharge refers to the downward movement of rainwater into aquifers, which can be hindered by adverse natural conditions and human development, while artificial recharge involves constructing structures to enhance this process.

Advantages:

- Address the decline of groundwater levels by enhancing availability,
- Sustaining drinking water sources,
- Improving irrigation well yields,
- Increasing urban recharge,
- Preventing flooding,
- Ensuring better groundwater quality through dilution.

Methods of Artificial Recharge

Surface Techniques: Methods to achieve this include limiting surface flow, capturing water on the surface, or distributing it, with key examples being Percolation Tanks, Check Dams, Ditch and Furrow Systems, and Flooding through over Irrigation.

Sub Surface Techniques: Water is introduced directly into aquifers through methods such as recharge pits, shafts, wells, or injection wells.

Combination of Surface-SubSurface Techniques: The previously mentioned surface and sub-surface techniques can be integrated for enhanced recharge interventions, such as utilizing a recharge well within a percolation tank.



Surface Recharge Check Dam



Sub Surface Well Recharge



Surface-Sub Surface Recharge

Suitable methods for water conservation and artificial recharge in agricultural fields

Rainfed agricultural fields effectively recharge natural water supplies, and by slightly raising levee heights, more water can be captured without harming crops, while water conservation structures like farm ponds and efficient irrigation techniques, such as drip and sprinkler systems, can optimize water use for irrigation and aquaculture.



Farm pond



Bore well recharge

Artificial Recharge in hilly areas

Bench Terrace is a strategically designed structure on slopes that creates leveled steps to slow water movement, enhance water retention, conserve soil moisture, and prevent erosion, while Contour Trenches, which are shallow excavations along contour lines, help retain runoff, stabilize slopes, and boost soil moisture and vegetation; additionally, rooftop rainwater harvesting is ideal for hilly areas, enabling the collection of rainwater for domestic use, and Spring Management involves constructing structures like gully plugs and recharge pits to capture runoff and replenish spring sources



Spring management



Bench terrace



Contour Trenching



Rain water harvesting

Low-cost interventions for artificial recharge

Functional and defunct wells can be repurposed for artificial recharge without new infrastructure, using only filtered rooftop rainwater in operational wells, while abandoned wells may also serve this purpose if they were previously productive, are partially collapsed, or can be converted with an inverted filter, but should avoid poor groundwater quality sources and those not tapping into aquifers.

Low-cost filters for artificial recharge structures

Locally available sand and stone chips can be used to fill the filter pit. Drums/Barrels can be used instead of constructing masonry walls within the recharge pits.

Considerations in the design and maintenance of recharge systems

Design the recharge pit or well to accommodate the roof catchment area and average rainfall, ensuring it can hold the water volume from peak rainfall, while establishing adequate depth to reach permeable layers and diameter based on site conditions and expected water volume.

For effective rainwater harvesting, utilize strong, corrosion-resistant materials like PVC or galvanized iron for gutters and downpipes, and avoid installing artificial recharge structures where groundwater is less than 3m deep post-monsoon, focusing instead on building rainwater storage systems in those regions. Use non-toxic roofing materials suitable for water collection, regularly inspect the system for any damage or clogs, and install mesh filters on gutter ends to keep out debris.

Install a desilting and filtration system with materials like sand, pebbles, and gravel to clean rainwater before it enters the recharge structure, and ensure that the recharge pit or well is positioned away from potential contaminants like septic tanks.

To maintain water quality, clean storage tanks and pipes annually before the monsoon, regularly remove contaminants from the roof, and periodically clean or replace filter materials to ensure efficient percolation. The depth of the recharge structure should remain 3 to 5 meters above the local groundwater level—typically not exceeding this level—to avoid potential contaminants in overland flow, especially if the groundwater is at 10 meters below the surface.

Conclusion

Recharging groundwater is essential for combating water scarcity and promoting sustainable management, with techniques like rain gutters empowering households to contribute, especially as climate change and population growth strain water resources, ensuring these systems are vital for a resilient future.

AUTHORS' DETAILS:

Abhishek Kumar¹

¹Assistant Professor,
Department of Veterinary
Clinical Complex (VGO),
COVAS, Kishanganj

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Commercial Pregnancy Diagnosis Kits for Early Pregnancy Detection in livestock

Abstract

Early and accurate pregnancy diagnosis is an important component of reproductive management in livestock. Failure to identify non-pregnant animals promptly can result in prolonged calving or kidding intervals, increased breeding costs, delayed rebreeding, and reduced farm profitability. Conventional methods such as transrectal palpation and ultrasonography are reliable when performed by trained personnel, but their availability may be limited in remote and smallholder farming areas. Commercial pregnancy diagnosis kits provide a simple alternative that can be used at the farm or field level. Depending on the technology, these kits detect pregnancy-associated glycoproteins (PAGs), which are produced by the developing conceptus and placenta, or measure progesterone concentrations associated with the corpus luteum. Rapid lateral-flow tests generally use blood, serum or plasma and can provide results within minutes, whereas ELISA-based tests are more suitable for laboratories and large-scale testing. Urine-based pregnancy tests have also attracted interest because sample collection is non-invasive and does not require blood sampling. However, the timing of testing, species, sample type, kit validation and interpretation of positive and negative results are critical for obtaining reliable results. This article focuses on major types of commercial pregnancy diagnosis kits available for livestock, their principles, advantages, limitations and potential applications under field conditions, with particular emphasis on cattle and buffaloes in India.

Introduction

Pregnancy diagnosis is one of the most important reproductive management practices in cattle, buffaloes, sheep and goats (Balhara et al., 2013; Karadaev, 2015). Identifying pregnant animals at an early stage allows farmers to manage pregnant and non-pregnant animals separately, improve feeding and health management, reduce unnecessary expenditure on breeding, and promptly rebreed animals that have failed to conceive. In dairy animals, early identification of non-pregnant animals is particularly important because every additional open day can negatively affect reproductive and economic efficiency (Lamb and Mercadante, 2016; Gnemmi et al., 2022).

Traditionally, pregnancy diagnosis has been performed by transrectal palpation or ultrasonography (Romano et al., 2006). These techniques can provide highly useful information about the reproductive tract and pregnancy, but they require trained personnel and, in the case of ultrasonography, access to appropriate equipment. Such facilities may not always be readily available to smallholder farmers in rural areas (Lobago et al., 2006; Karen et al., 2007).

Commercial pregnancy diagnosis kits have therefore emerged as an attractive field-level option. These tests are generally designed to detect biological substances associated with pregnancy in blood, serum, plasma, milk or urine (Reese et al., 2016). Among them, pregnancy-associated glycoprotein (PAG)-based tests have received considerable attention because PAGs are produced by specialized trophoblastic cells of the developing conceptus and placenta. Their presence in maternal circulation can therefore provide evidence of pregnancy (Green et al., 2000; Wallace et al., 2015). Another approach is based on progesterone, a hormone produced primarily by the corpus luteum. Progesterone testing does not directly detect the fetus or placenta. Instead, it determines whether progesterone remains elevated after breeding (Karen et al., 2003). Consequently, progesterone tests are particularly useful for identifying animals likely to be non-pregnant, but a high progesterone concentration should not automatically be interpreted as definitive evidence of pregnancy.

Major Types of Commercial Pregnancy Diagnosis Tests

Commercial livestock pregnancy tests can broadly be divided into three categories:

1. PAG-based rapid lateral-flow tests
2. PAG-based laboratory ELISA tests
3. Progesterone-based pregnancy tests
4. Urine-based pregnancy tests

PAG-Based Rapid Visual Tests

Rapid PAG tests are generally designed as lateral-flow immunoassays. They resemble the basic format of rapid diagnostic tests used in human medicine. A small quantity of biological sample is placed on a test cassette, and pregnancy-associated proteins present in the sample react with antibodies incorporated into the test device. The result is subsequently indicated by the appearance of colored lines.

Depending on the product and species, the sample may be whole blood, serum or plasma. Some tests have been developed or marketed for use in cattle, buffaloes, sheep and goats.

One of the major advantages of these tests is their speed. Results may become available within approximately 10–30 minutes, depending on the

product and protocol. This makes them potentially useful for veterinary camps, artificial insemination programmes, commercial dairy farms and field reproductive-management services.

Laboratory ELISA Tests

ELISA-based pregnancy diagnosis is another important application of PAG detection. In these tests, antibodies are used to detect PAGs in a biological sample. Unlike individual rapid cassettes, ELISA allows many samples to be processed simultaneously. ELISA kits are commonly supplied in microplate formats, often allowing dozens of samples to be analyzed in a single batch. Samples may include serum, plasma or milk, depending on the test system. Milk-based pregnancy testing can be particularly useful in dairy herds because samples can potentially be collected during routine milking without venipuncture. However, laboratory ELISA requires appropriate equipment, reagents, trained personnel and sample handling facilities. Consequently, it is more suitable for veterinary laboratories, diagnostic centres, research institutions and large dairy operations than for individual smallholder farmers.

Pregnancy-associated glycoproteins are produced by the trophoblast or placenta during pregnancy. After conception and development of the conceptus, PAGs enter the maternal circulation and can subsequently be detected in blood.

The basic principle can be summarized as:

Conception → conceptus/placental development → PAG production → PAG enters maternal circulation → PAG detected by diagnostic test → pregnancy indicated

Because PAGs are associated with pregnancy rather than simply ovarian luteal activity, PAG-based testing has an important advantage over progesterone testing. However, PAG concentration does not become immediately detectable following fertilization. Therefore, testing too early can result in a false-negative result. The earliest reliable testing day depends on the species, assay and manufacturer's validation.

For this reason, a farmer should not assume that every PAG kit can be used on the same day after mating or artificial insemination.

Urine-Based Pregnancy Diagnosis

Urine-based pregnancy diagnosis is particularly attractive in developing livestock-production systems because urine collection is non-invasive and does not require a blood sample.

In India, indigenous approaches to urine-based pregnancy diagnosis have received considerable attention. Preg-D, associated with ICAR-CIRB, is an example of an Indian-developed approach for pregnancy diagnosis in cattle and buffaloes. Such tests are intended to provide a simple field-level method that can be used where access to ultrasonography and laboratory facilities is limited.

Commercial urine-based pregnancy tests are also available in the Indian market, including products marketed under names such as Gavyam. These products are promoted for rapid field testing, although their recommended testing age, biological target, sensitivity and specificity should be assessed from the manufacturer's validation data before making clinical decisions.

The principal advantage of urine testing is its simplicity. A farmer or field worker does not necessarily need to collect blood, and the procedure can potentially be performed with minimal equipment. However, ease of sample collection should not be confused with diagnostic certainty. The test must be validated for the species, physiological stage and intended day after breeding.

Progesterone-Based Pregnancy Testing

Following ovulation, the corpus luteum develops and produces progesterone. If pregnancy does not occur, luteolysis normally takes place toward the end of the estrous cycle, resulting in a fall in progesterone. If pregnancy is established, the corpus luteum is maintained and progesterone generally remains elevated.

The basic principle is therefore:

Ovulation → corpus luteum formation → progesterone increases

If the animal is not pregnant:

Corpus luteum regression → progesterone decreases → return to estrus

If pregnancy is maintained:

Pregnancy recognition → corpus luteum maintained → progesterone remains elevated

Progesterone can be measured in milk or blood, and milk progesterone testing has practical advantages in dairy animals.

Category	Kits/examples	What they detect
PAG-based	Alertys, Pregnostx, BovEasy, Bignano, AuraSure, AniEasy, PregKine	Pregnancy-associated glycoproteins/ pregnancy-associated biomarkers
Urine-based	Preg-D, Gavyam	Pregnancy-associated urinary marker/metabolite, depending on test principle
Progesterone-based	P4 Rapid, Target Bovine, Ringbio	Progesterone/functional corpus luteum

Why timing is critical

Progesterone testing is highly dependent on the stage of the estrous cycle. A high progesterone concentration does not necessarily mean that an animal is pregnant because a normal functional corpus luteum can also produce high progesterone during the luteal phase of a non-pregnant cycle.

For example, testing a cow at approximately 21 days after insemination may provide useful information about whether luteolysis has occurred. However, interpretation becomes more complicated if the cow has an unusually long or short cycle, has an ovarian disorder, or has experienced embryonic loss.

Therefore, low progesterone around the expected return-to-estrus period is a strong evidence that the animal is not maintaining a functional luteal phase. Progesterone testing is consequently better regarded as a tool for reproductive status assessment rather than a direct pregnancy test.

Feature	PAG-based test	Progesterone-based test
Biological target	Pregnancy-associated glycoproteins	Progesterone
Indicates	Presence of conceptus/placental activity	Presence of functional corpus luteum
Common samples	Blood, serum, plasma, milk	Mainly milk or blood
Early pregnancy detection	Generally more directly pregnancy-specific	Indirect
High result	Supports pregnancy	Does not necessarily confirm pregnancy
Low result	May indicate non-pregnancy, depending on timing	Strong evidence against a functional luteal phase
Field application	Very useful	Useful, particularly for dairy reproductive monitoring
Major limitation	Very early testing can produce false negatives; residual PAG after pregnancy loss can complicate interpretation	High progesterone can occur in non-pregnant animals

Pregnancy Diagnosis in Indian Dairy Farming

The Indian livestock sector presents a particularly strong need for simple pregnancy-diagnosis technologies. Millions of cattle and buffaloes are managed by small and marginal farmers, often in areas where veterinary diagnostic services and ultrasonography are not immediately accessible.

Buffaloes are especially important in the Indian dairy sector. Consequently, pregnancy-diagnosis technologies specifically evaluated for buffaloes are

highly relevant.

A useful field diagnostic system should ideally be:

- inexpensive;
- simple to perform;
- rapid;
- minimally invasive;
- stable under field conditions;
- suitable for the target species;
- easy to interpret;
- And sufficiently accurate for reproductive decision-making.

No single test satisfies all these requirements under every situation. Therefore, pregnancy kits should be considered complementary tools rather than complete replacements for veterinary examination.

Important Precautions before Using a Pregnancy Kit

1. Test at the correct time

The most common reason for a misleading result is testing at an inappropriate stage after breeding.

2. Use the correct sample

A kit validated for serum or plasma should not automatically be assumed to work equally well with whole blood or milk.

3. Follow species-specific recommendations

A test validated for cattle should not automatically be assumed to have identical performance in buffaloes, sheep or goats.

4. Do not rely on a positive result alone

Particularly with progesterone-based testing, a high hormone concentration does not prove pregnancy.

5. Consider pregnancy loss

PAGs may remain detectable for some time after pregnancy loss, depending on species, stage of pregnancy and assay. Therefore, a positive result should be interpreted in relation to the timing of the test and the animal's reproductive history.

6. Confirm doubtful results

Animals with uncertain, unexpected or clinically inconsistent results should be examined by a veterinarian. Ultrasonography remains particularly valuable because it can provide information about the uterus, conceptus and ovarian structures in addition to pregnancy status.

The choices one should make depend mainly on the

purpose and available resources.

For smallholder farmers: A simple, validated urine-based or rapid blood-based test may be useful where veterinary facilities are limited.

For artificial insemination technicians and field veterinarians: Rapid PAG-based blood tests can provide a practical method for screening several animals during reproductive-management visits.

For large dairy farms: Milk or blood-based ELISA may be advantageous when many animals need to be tested systematically.

For diagnostic confirmation: Ultrasonography performed by a trained veterinarian remains highly valuable because it provides considerably more reproductive information than a simple pregnancy test.

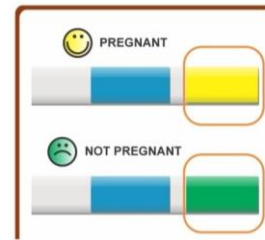
Conclusion

Commercial pregnancy diagnosis kits are increasingly useful tools for improving reproductive management in cattle, buffaloes, sheep and goats. Their major advantage is the possibility of obtaining a pregnancy-related result without depending entirely on transrectal palpation or access to an ultrasound machine. PAG-based tests provide a more pregnancy-specific approach by detecting pregnancy-associated glycoproteins, whereas progesterone-based tests assess the hormonal status of the corpus luteum and therefore provide indirect evidence of pregnancy. Urine-based tests offer an additional attractive option for field conditions because sample collection is simple and non-invasive.

For Indian dairy farmers, particularly those in rural and resource-limited areas, these technologies could help identify non-pregnant animals earlier and facilitate timely rebreeding. Nevertheless, a pregnancy kit should not be viewed as a substitute for professional reproductive examination in every situation. Correct timing, species-specific validation, appropriate sample collection and proper interpretation are essential for reliable results. When used appropriately and combined with good estrus detection, artificial insemination records and veterinary reproductive examination, rapid pregnancy diagnosis can become an important component of cost-effective reproductive management and improved livestock productivity.

Pregnancy-Associated Glycoproteins (PAGs) based pregnancy diagnosis kit





Progesterone (P₄) based pregnancy diagnosis kit



Urine based pregnancy diagnosis kit



#AgrilInnovation

Preg-D
PROGESTIN
30 minutes to pregnancy diagnosis in Buffalo & Cow

PREG D URINE - BASED PREGNANCY DIAGNOSIS KIT FOR COW AND BUFFALOES

Features

- Ease of use based - on urine, so non invasive
- No cold chain/ refrigeration required for kit and urine samples
- Per sample cost 5-10 Rs
- Reading of results by naked eye

Developed by
Dr. Ashok Kumar Balhara, et. al.
ICAR-CENTRAL INSTITUTE FOR RESEARCH ON BUFFALOES, HISAR





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AUTHORS' DETAILS:

Pragati Dhanda¹,
Shikha Mehta*,
Rajesh Gera¹,
Kamla Malik¹,
Jyoti Yadav¹
Ruchika¹

¹College of Basic Sciences &
Humanities
CCS HAU
Hisar, 125004,
Haryana, India

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Microalgae-Based Bioethanol: Processes, Applications, and Future Prospects

Abstract

The growing demand for sustainable energy has increased interest in renewable alternatives to fossil fuels, with bioethanol emerging as a promising clean fuel. Microalgae have attracted a lot of interest because of their high biomass productivity, low cost, and high carbohydrate content, in addition to their ability to grow in saline water or wastewater without competing with food crops. The potential benefits of microalgae as feedstocks in comparison to conventional biomass sources are discussed in this article and the key stages in the production of bioethanol from these microalgae are summarised: cultivation, harvesting of the biomass, pretreatment, hydrolysis, fermentation and ethanol recovery. It also discusses the applications of bioethanol and the role of the microalgal biorefinery approach in improving process sustainability. Although there are difficulties to large-scale commercialisation, further technological developments are expected to improve the viability of microalgal bioethanol production in future renewable energy systems.

Keywords: Bioethanol, Biorefinery, Biomass, Microalgae, Renewable energy, Sustainability

1.Introduction

The increasing energy demand, declining fossil fuel reserves, and rising environmental concerns have intensified the search for clean, renewable, and sustainable energy sources. However, the widespread adoption of fossil fuels has led to significant greenhouse gas emissions, climate change and environmental degradation, making biofuels a promising alternative for a sustainable energy future (Wang et al., 2024).

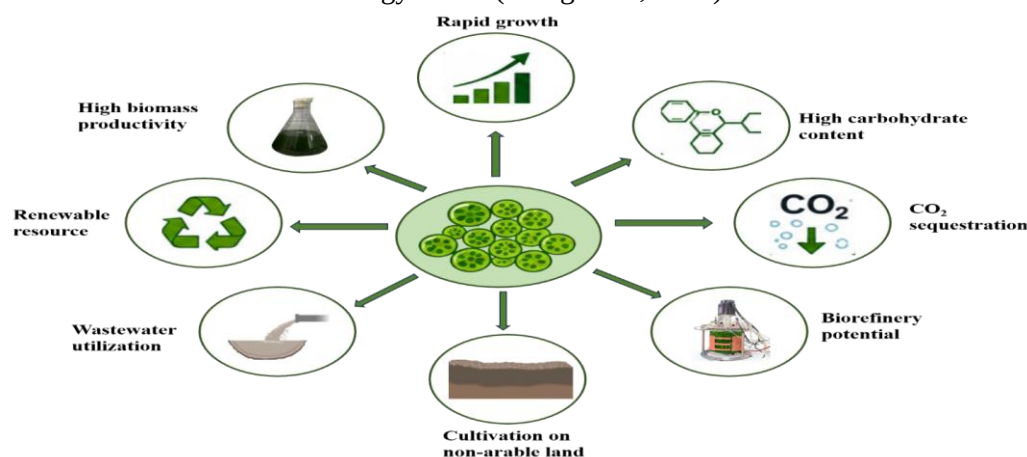


Figure 1. Advantages of Microalgae as a Sustainable Feedstock for fuel production

Bioethanol is a widely used biofuel as it is biodegradable, generates lower carbon emissions and is compatible with existing fuel infrastructure. Its primary source is sugar- and starch-rich crops, including sugarcane, corn, and wheat, but the extensive use of these crops is a concern due to competing demands for land and water and potential impacts on food security (Kumari et al., 2024).

The potential fuels that have been identified as a third-generation biofuel are microalgae because of their fast growth rate, high photosynthetic efficiency and efficient use of carbon dioxide. *Chlorella vulgaris*, *Scenedesmus obliquus* and *Chlorella sorokiniana* are examples of species that can store high amounts of carbohydrate, which could be fermented into fermentable sugars and used as potential renewable biomass for bioethanol production (de Carvalho Silvello et al., 2023; Effiom et al., 2023).

2. Why Microalgae for Bioethanol?

Microalgae are emerging as a source of third generation bioethanol due to their great biological and environmental benefits. In contrast to traditional feedstocks like sugarcane and corn, microalgae do not require valuable arable land and can be grown using saline water, seawater, or nutrient-rich wastewaters, which helps conserve freshwater and aids in wastewater treatment (Wang et al., 2024; Bora et al., 2024).

They are fast-growing, have high photosynthetic efficiency and high biomass productivity, which allows them to yield higher biomass than many terrestrial crops, as well as capturing atmospheric CO₂ efficiently. The species like *Chlorella sorokiniana* and *Scenedesmus obliquus*, which are rich in carbohydrates, are the potential feedstocks for bioethanol production. Besides this, the residual biomass can be used for the production of protein, pigments, and biofertilizers through a biorefinery approach, thereby enhancing the sustainability and economic worth of the process (Kumari et al., 2024; Ho et al., 2013; Kaur et al., 2022). The salient features of using microalgae as sustainable bioethanol feedstocks are shown in Figure1, while their comparison with conventional feedstocks is presented in Table 1.

4. Steps involved in bioethanol production from microalgae

The production of bioethanol from microalgae has a number of interrelated steps, such as cultivation, harvesting, pretreatment, hydrolysis, fermentation, and recovery of ethanol. The yield and efficiency of the process is governed at each stage.

I. Cultivation and Biomass Production

The first step in the process is to grow the microalgae (carbohydrate rich) like *Chlorella vulgaris* and *Scenedesmus* sp. The microalgae grow in open pond or photobioreactor in controlled conditions of light, temperature, pH and nutrient supply.

Table 1. Comparison of Conventional Feedstocks and Microalgae for Bioethanol Production

Characteristic	Conventional Feedstocks (e.g., Sugarcane, Corn)	Microalgae	References
Food competition	Compete with food crops, potentially affecting food security	Can be cultivated without competing with food crops	Wang et al. (2024); Kumari et al. (2024)
Land requirement	Require fertile agricultural land	Can be cultivated on non-arable, marginal, or wastelands	Wang et al. (2024); Pandit et al. (2025)
Water requirement	Primarily dependent on freshwater	Can be cultivated using saline water, seawater, or wastewater	Bora et al. (2024); Karthikeyan (2023)
Biomass productivity	Moderate and seasonal	High biomass productivity with rapid growth under controlled conditions	Wang et al. (2024); Karthikeyan (2023)
Carbohydrate accumulation	High, depending on crop species	Moderate to high; carbohydrate content can be enhanced through nutrient optimization	de Carvalho Silvello et al. (2023); Kumari et al. (2024)

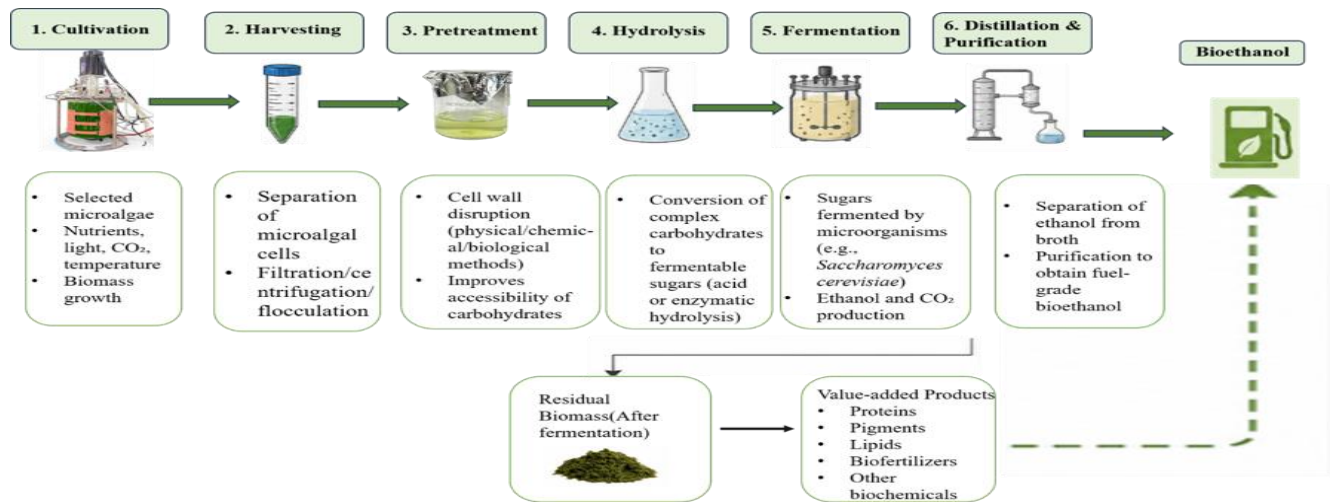


Figure 2. Schematic Representation of Bioethanol Production from Microalgae

Optimizing these factors, in particular nitrogen limitation, allows for more efficient accumulation of carbohydrates and better quality of biomass for bioethanol production (de Carvalho Silvello et al., 2023; Wang et al., 2024).

II. Biomass Harvesting

The biomass is collected from the culture, e.g. by flocculation, filtration and/or centrifugation. Efficient harvesting not only reduces the loss of algal biomass, but also concentrates the algal biomass and prepares it for downstream processing (Wang et al., 2024).

III. Pretreatment and Hydrolysis

Cell wall must be broken down to liberate the intracellular carbohydrates, which is accomplished by pretreatment. The biomass is then treated with acids or enzymes to break down the complex carbohydrates to fermentable sugars needed for bioethanol production (Effiom et al., 2023; Agarwalla et al., 2023). The major steps involved in the production of bioethanol from microalgae are illustrated in Figure 2.

IV. Fermentation and Ethanol Recovery

The fermentable sugars are converted to bioethanol using microorganisms usually *Saccharomyces cerevisiae*. The ethanol, thus, produced is recovered by distillation and purification. A biorefinery approach can be used to make the process more sustainable by using the residual biomass for the production of other valuable products, such as

proteins, pigments, lipids, and biofertilizers (Condor et al., 2022; Kumari et al., 2024; Bahmani et al., 2024).

5. Applications of Bioethanol

Bioethanol is a clean and renewable fuel with numerous applications in the energy, transportation, and industrial sectors. In order to lower greenhouse gas emissions, enhance fuel combustion, and lessen reliance on fossil fuels, it is frequently mixed with gasoline. Other than its use as a fuel for transportation, it is also a valuable raw material in chemical, pharmaceutical, cosmetic and food industries, for the production of solvents, disinfectants etc., and other industrial products (Wang et al., 2024; Kumari et al., 2024).

Bioethanol production from microalgae also provides further environmental benefits since it is coupled with carbon dioxide sequestration and also can be combined with wastewater treatment. Additionally, a biorefinery approach can facilitate the recovery of valuable co-products such as proteins, pigments, lipids, and biofertilizers, enhancing the economic and environmental sustainability of the entire process (Pandit et al., 2025; Bahmani et al., 2024).

6. Conclusion

Microalgae are considered to be a potential and sustainable feedstock for bioethanol production due to their fast growth, high biomass productivity and ability to store carbohydrates without being in competition with food crops and fertile agricultural land. Further improvements to their environmental and economic benefits are achieved by cultivating

them with saline water, wastewater and industrial carbon dioxide. The production of bioethanol from microalgae is still challenging due to high production costs and commercialization on large scale but there is continuous progress in the cultivation technologies, biomass processing and integrated biorefinery approaches which are making the technology more feasible. As research and technology continue to advance, microalgae can be a significant factor in future renewable energy needs and contribute towards a more sustainable and environmentally-friendly bioeconomy.

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AUTHORS' DETAILS:

Jesreen Chauhan*¹,
Julie Dogra Bandral¹,
Monika Sood¹,
Arushi Sharma¹

*Division of Post Harvest
Management,
Sher-e-Kashmir University of
Agricultural Sciences and
Technology-
Jammu, 180009,
Jammu and Kashmir*

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Transforming Post-Harvest Losses into Nutritious Food Products

Abstract

Post-harvest loss is not simply a problem of food that fails to reach the market; it also represents wasted nutrients, labour, water, energy and economic opportunity. Fruits and vegetables are especially vulnerable because of their high moisture content, active metabolism and sensitivity to bruising, temperature changes and microbial spoilage. At the same time, surplus, cosmetically imperfect produce and processing residues such as peels, seeds and pomace can contain valuable fibre, pigments and bioactive compounds. This article discusses how appropriate processing, fermentation, drying, extraction and product development can convert these materials into safe, nutritious and marketable foods. It also highlights the importance of food safety, sustainable processing, farmer participation and circular food systems. The central message is simple: preventing losses should come first, but material that is safe for consumption can often be given a second life as a useful food ingredient or product.

Keywords: Post-harvest losses, Food loss valorization, Horticultural crops, Value addition, Functional foods, Sustainable food processing.

Introduction

Every year, a substantial proportion of fruits and vegetables produced globally never reaches the consumer in its original form. According to the latest FAO data, roughly 13.3% of the world's food is lost between harvest and retail each year, equivalent to about 1.31 billion tonnes of production and fruits and vegetables consistently record the highest losses of any commodity group, having risen from 23.2% in 2015 to 25.4% in 2023 [1][2]. Sub-Saharan Africa suffers the steepest losses at around 23%, while North America and Europe report the lowest, at about 10% [2]. These figures do not even include the additional 17–19% of food wasted further down the chain, at retail, food-service and household level [1]. These losses represent much more than an economic setback; FAO estimates the pre-retail losses alone at close to USD 400 billion a year [1]. They also mean wasted water, energy, labour, land and valuable nutrients invested in producing the food, and food loss and waste together account for an estimated 8–10% of global greenhouse gas emissions [1]. However, what is considered a "loss" at one stage of the food chain does not necessarily have to become waste. With appropriate processing and value-addition technologies, many surpluses, cosmetically imperfect and processing-derived horticultural materials can be transformed into nutritious, safe and marketable food products. This approach provides an opportunity to move from a traditional "produce–consume–discard" model towards a more sustainable and circular food system.

Understanding Post-Harvest Losses

Post-harvest losses occur between harvesting and final consumption. Fruits and vegetables are particularly vulnerable because of their high moisture content, active metabolism and sensitivity to mechanical injury, temperature fluctuations and microbial deterioration. Losses may occur during harvesting, sorting, grading, packaging, transportation, storage, processing, marketing and retailing. In addition to complete deterioration, a considerable quantity of produce may be commercially rejected despite remaining suitable for consumption. Fruits that are too small, unusually shaped, slightly blemished or overripe are often removed from conventional supply chains even though their nutritional value may remain largely intact. Processing industries generate another important stream of potentially valuable material. Peels, seeds, pomace, pulp residues and other by-products are frequently treated as waste. For example, the global citrus-processing industry alone generates an estimated 15–32 million tonnes of peel, seed and pomace waste every year, with these residues making up nearly half the fruit's total mass [3]. Yet many of these materials contain dietary fibre, phenolic compounds, pigments, minerals, vitamins and other bioactive constituents. Thus, the challenge is not simply to reduce post-harvest losses, but also to recover value from materials that are no longer suitable for sale as fresh produce.

From Waste to Food: A Change in Perspective

The concept of food loss valorization focuses on converting underutilized horticultural materials into useful products rather than allowing them to become waste. This can include fresh produce that is visually imperfect, surplus produce during peak seasons, overripe fruits and residues generated during processing. For example, excess fruit can be processed into juices, beverages, purees, jams, jellies, fruit leathers, powders and fermented products. Vegetable surpluses can be converted into dehydrated products, soups, sauces, pickles, chutneys, powders and ready-to-use ingredients. Similarly, fruit peels and seeds can be processed to recover valuable compounds or incorporated into suitable food formulations after

appropriate safety and processing considerations. This approach has two major advantages: it reduces the quantity of material entering the waste stream while creating additional nutritional and economic value. Recent reviews describe fruit and vegetable waste valorization as a genuine circular-economy strategy, with recovered materials finding uses not only in food but in packaging, agriculture, water purification and industrial applications [4].

Turning Imperfect Fruits into Nutritious Products

Aesthetic standards are one of the often-overlooked contributors to food loss. Consumers and markets frequently prefer fruits with uniform size, shape and colour. As a result, perfectly edible fruits that do not meet visual standards may be rejected. Instead of discarding such produce, it can be redirected towards processing. Overripe bananas, for instance, can be used in purees, bakery products and fruit-based snacks. Surplus mangoes can be converted into pulp, nectar, dried products and fruit leather. Excess berries can be processed into beverages, preserves and functional ingredients. Similarly, locally available underutilized fruits can be explored for the development of novel products with regional identity. Processing also provides an opportunity to extend the availability of highly perishable fruits beyond their short harvest season.

Fruits and Vegetables as Sources of Functional Ingredients

One of the most promising areas of food-loss valorization is the recovery of bioactive compounds. Fruit and vegetable materials can contain phenolic compounds, flavonoids, carotenoids, anthocyanins and other phytochemicals associated with antioxidant and other biological activities. Depending on the commodity, peels and other tissues may contain considerable concentrations of these compounds; recent analyses across twenty different crops report total phenolic content ranging from roughly 50 to 300 mg (gallic acid equivalents) per gram of dry residue, anthocyanins up to around 600 mg per gram, and flavonoids up to about 150 mg per gram, depending heavily on the crop and extraction method used [5].

These are substantial concentrations that go largely unused when the material is simply discarded. These components can potentially be incorporated into food products as natural colorants, antioxidants, flavoring ingredients or sources of dietary fibre. Beyond food, the same compounds are increasingly being explored for antimicrobial, antioxidant and even antitumoral applications in nutraceuticals, dermo-cosmetics and biomedicine, one recent review noted that vegetable waste generation in European countries alone ranged from 35 to 78 kg per person in 2022, underlining both the scale of the by-product stream and its untapped potential [6]. For example, brightly colored fruit materials may serve as sources of natural pigments, while fruit pomace can provide fibre-rich ingredients. However, the nutritional and functional potential of a by-product must be evaluated scientifically, since composition varies considerably with crop, variety, maturity, processing conditions and storage history.

Innovative Products from Horticultural Surplus

The food industry can utilize several approaches to transform surplus horticultural produce into convenient and nutritious products. Dehydration is one of the oldest and most practical methods. Removing moisture reduces microbial growth and extends shelf life while producing lightweight products that are easier to transport and store. Fruits and vegetables can be converted into dried slices, powders and flakes. Fruit powders are particularly interesting because they can be incorporated into beverages, bakery products, confectionery, breakfast foods and nutraceutical formulations. Fermentation represents another promising approach. Fruits and vegetables can serve as substrates for the production of fermented beverages and other foods. Fermentation may not only improve shelf life and sensory characteristics but can also modify the composition and bioavailability of certain phytochemicals. Fruit leathers and snack products provide another avenue for utilizing surplus or cosmetically imperfect fruits. By combining different fruits, herbs or natural ingredients, processors can create products with distinctive flavors and improved nutritional profiles. Purees, sauces, chutneys and spreads can also provide

practical solutions for seasonal surpluses while creating products with higher market value than the original raw material.

The Role of Green Processing Technologies

The transformation of food losses into valuable products must itself be sustainable. Conventional processing can sometimes involve considerable energy consumption or generate secondary waste. Therefore, modern approaches increasingly focus on technologies that preserve nutritional quality while minimizing environmental impact. Freeze-drying, vacuum drying, microwave-assisted drying, ultrasound-assisted extraction and other advanced technologies can be explored for specific applications. Recent literature highlights ultrasonication, supercritical fluid extraction and enzyme-assisted extraction as particularly effective for maximizing the recovery of bioactive compounds while preserving their activity [7][3]. These technologies may help improve the retention or recovery of sensitive compounds, although their economic feasibility must always be considered. Green extraction approaches are particularly relevant when recovering bioactive compounds from fruit and vegetable residues. The objective is to obtain useful compounds while minimizing the use of hazardous solvents, energy and water.

Safety Must Come Before Valorization

Not every material classified as "waste" is suitable for conversion into food. Produce affected by mould growth, serious microbial contamination, chemical contamination or advanced deterioration should not be incorporated into food products merely to prevent waste. Valorization must always operate within food-safety requirements. Proper sorting is therefore essential. Materials intended for food applications should be clean, traceable and appropriately handled. Processing conditions, storage stability, microbial safety and potential contaminants must be carefully evaluated before a product reaches consumers. The principle should be simple: food that is safe and nutritious should be rescued; food that is unsafe should not be rescued for human consumption.

Opportunities for Farmers and Small-Scale Entrepreneurs

Food-loss valorization does not belong exclusively to large food-processing companies. It can create opportunities for farmers, self-help groups, cooperatives, rural entrepreneurs and small processing units. During peak harvest periods, when market prices may decline because of oversupply, processing can provide an alternative route for utilizing surplus produce. Small-scale units can produce dried fruits, powders, preserves, beverages, pickles, chutneys and other shelf-stable products. This can increase farmers' income, reduce dependence on fresh-market prices and create local employment. This is especially significant in regions with the highest recorded losses; FAO's data show Sub-Saharan Africa, least-developed countries and small island developing states all losing close to a fifth or more of their fruit and vegetable production before it even reaches the market [2]. For regions rich in diverse but underutilized horticultural resources, such an approach can be particularly valuable. Local fruits, berries, herbs and other crops can become the foundation for region-specific food products rather than remaining underexploited resources.

Building a Circular Food System

The ultimate goal of food-loss valorization is not simply to manufacture more products. It is to create a more efficient food system in which resources remain useful for as long as possible. A circular approach begins with preventing losses wherever possible. Produce should be harvested at the appropriate maturity, handled carefully, stored under suitable conditions and transported efficiently. Materials that cannot be marketed fresh but remain safe for consumption can then be directed towards processing and value addition. Only after opportunities for human consumption have been exhausted should other routes, such as animal feed, industrial applications, composting or bioenergy, be considered where appropriate. This hierarchy ensures that the highest possible nutritional and economic value is retained, and directly supports progress towards SDG Target 12.3, which calls for halving per-capita global food

waste and reducing food losses along production and supply chains by 2030 [2].

The Way Forward

Transforming post-harvest losses into nutritious food products requires collaboration across the entire food chain. Researchers need to identify suitable crops, processing methods and bioactive components. Farmers and processors need access to affordable technologies. Entrepreneurs need market opportunities and consumer awareness. Policymakers can support the development of infrastructure, training and food-processing enterprises. Most importantly, consumers need to recognize that quality is not determined by appearance alone. A slightly blemished apple, an unusually shaped vegetable or an overripe fruit can still contain valuable nutrients and can potentially become the raw material for an entirely different food product. The future of food security is not only about producing more food. It is also about using the food we already produce more intelligently. Post-harvest losses therefore should not be viewed solely as an unavoidable consequence of agricultural production. They can also represent an opportunity for innovation. Through appropriate processing, fermentation, drying, extraction and product development, surplus and underutilized horticultural resources can be transformed into nutritious, safe and commercially valuable foods. What was once considered waste can become an ingredient. What was once a loss can become an opportunity. And what begins as a post-harvest challenge can ultimately contribute to better nutrition, greater farmer income, reduced environmental pressure and a more sustainable food system.

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AUTHORS' DETAILS:



Sudhir Sharma

*Retired senior officer from
 NABARD,
 Post Graduate in Economics,
 CAIIB,
 MBA - Finance,
 PGDM - HR,
 Post Graduate Diploma in
 Environment Law & Policy
 (NLUD/WWF).
 He has vast experience of
 working in Financial Inclusion,
 Institutional Development &
 Credit Planning.*

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Self Sufficiency In Pulses - Past Performance and Strategic Goals

1. Introduction

Pulses have traditionally been a dominant part of a standard Indian diet, but owing to heightened nutritional awareness, they are being consciously included in the diet for health & wellness, and addressing protein deficiency concerns. Being highly nutritious, rich in proteins, fibre, vitamins and complex carbohydrates, pulses occupy a special place in the Indian food basket. For decades India has been the largest consumer of pulses in the world, with consumption now around 27% of global consumption. With the rising popularity of plant based diets, growing urbanisation, rising population and increase in purchasing power, demand of pulses is estimated to grow at 4.5 to 5% annually. Hence enormous work and several strategic measures have become essential to accelerate pulse production, achieve self-sufficiency, and reduce India's dependence on imports.

We have examined the trends related to the pulses sector over the last decade in the following paragraphs.

2. Production and Demand Trends

Food grains production in 2014-15 was 252 Mt, which increased to 357 Mt in 2024-25, while production of pulses increased from 17.2 Mt. to approx 25 Mt during this period. However of the 12 different pulses produced in India in 2024-25, only four pulses constituted 87% of production which are: (a) Chick Pea including kala chana, kabuli chana and green chana - 15.35 MT (b) Pigeon Pea (arhar/tur) - 3.62 MT (c) Black Gram (Urad) - 1.3 MT and (d) Red Lentils (Masur) - 1.6 MT. Another notable feature of pulses production is that 10 states (MP, Maharashtra, Rajasthan, UP, Karnataka, Gujarat, Andhra Pradesh, Telengana, Jharkhand and Tamil Nadu) contribute more than 90% of total output. Rajasthan is the third largest producer (after Madhya Pradesh and Maharashtra), achieving an impressive pulse production growth rate of 8% in the past decade contributing 48% of total moong bean and 97% of total moth bean produced in the country. However, owing to high domestic demand, the total production of all pulses is not adequate, making us globally the largest importer of pulses.

Demand projection for pulses, as carried out in Niti Aayog Report on pulses has considered changes in behaviour of consumption of different food items due to per capita income and price changes, income elasticity, population projections, and base year per capita availability. Based on this approach the demand for pulses is projected to reach 35.16Mt by 2030 and 50.73 Mt by 2047, while national level pulses supply is projected to be 30.6 Mt by 2030 and 45.76 Mt by 2047 leaving a gap of 4.5 Mt by 2030.

3. Consumption Trends

The average consumption of pulses as per 68th round of NSSO survey was 28.2 gms per day for the 2011-12 period. However, for the 2023-24 period, NSSO reports show that the average consumption was approx 24.7 gms per day in rural areas and 26.7 gms in urban areas, which is marginally lower than the consumption in 2011-12 period. If we take into account production plus imports, there is certainly higher per capita availability of pulses of 40-45 gms per day, but the actual intake has remained low both in rural and urban areas due to wastage, accessibility issues and seed use. This level of consumption also falls short of the ICMR recommended intake of 40-60 grams of protein and fibre per person per day.

4. GoI Mission for Self Sufficiency

In October 2025 Govt launched a six-year initiative entitled the "Mission for Aatmanirbharta in Pulses" with focus on pigeon pea (arhar), black gram (whole urad), and lentil (masoor) involving a total outlay of Rs 11400 crores for the period 2025-26 to 2030-31. The Mission aims to achieve annual production of 35 Mt by 2030-31, and expand the area under pulses cultivation by 3.5 Mha. Higher yield and expansion of area under pulses through a cluster approach are the two key pillars of the strategy under the Atmanirbharta Mission, prioritising district level clusters by classifying them as - Low Area - Low Yield (LA- LY), High Area - Low Yield (HA-LY) and Low Area - High Yield (LA-HY) to be taken up with appropriate technological interventions. Mission objectives also include yield improvement to 1130 Kg/ha, distribution of 128 lakh quintals of certified seeds and 88 lakh seed kits to farmers.

5. Past Performance in Terms of Area and Yield

(i) Area under pulses increased from 23.5 M ha in 2014-15 to 27.3M ha in 2024-25. During 2017-18 the area had reached a high of 29.8 M ha, and it touched 31M ha in 2021-22, as farmers brought more area under pulses due to increase in pulse prices during that period. However, past trends show that area has not increased consistently in proportion to population growth and overall

agriculture land expansion, mainly because the yield improvement and procurement policies towards cereal crops made wheat & rice more competitive. However, bringing additional 3.5 Mha (as planned under the Mission) appears achievable through the stated horizontal expansion by several measures, inter alia growing pulses in rice fallow areas, intercropping of pulses with sugarcane, millets & vegetables, and introduction of summer pulses after harvest of wheat, mustard and pea.

(ii) Yield has a very significant role in production of pulses. India's pulse yield has been around 800-1000 Kg/ha which is significantly lower than major producers like Canada, Australia and Russia with 1500-2000 Kg/ha. Yield gap also exists between the yield from demonstration plot and that which farmers get from their field. Furthermore, the yield gap across states is very wide - for instance average yield of pulses in MP and Gujarat is much higher than yield in states like Karnataka and Rajasthan. Chick pea (bengal gram) and pea (matar) exhibited a relatively high yield level among major pulses, increasing from 630 Kg/ha in the 1980s to 1000-1060 Kg/ha in 2024-25 over a period of 40-45 years, while Pigeon pea (arhar) has shown limited growth in yield from 700Kg/ha to approx 850 Kg/ha in 1980s to 2024-25 period. Black gram (urad), lentils (masoor) and moth bean have shown the lowest yields compared to other pulses. Going by the production data of pulses for the last 10 years, which increased from 17.2 Mt to 25 Mt in the 2014-15 to 2024-25 period, increase in annual production to 35Mt by 2030 as a Mission target seems very challenging unless the yield is improved considerably.

(iii) We may recall that Mini Missions and various pulse projects in the past provided a lot of field experience to implementing agencies in ground level implementation, and resulted in some encouraging results in production technologies and yield improvements. First project in this direction was the All India Coordinated Pulses Improvement Project (AICPIP) launched in 1966

by ICAR which focussed on R&D activities for pulses sector. Other subsequent programmes for pulses could not be called transformative success but they laid the groundwork for subsequent initiatives. Notable among the other projects are National Pulses Development Project (NPDP); Integrated Scheme of Oil Seeds Pulses, Oil Palms & Maize (ISOPOM); National Food Securities Mission - Pulses (NFSM); Accelerated Pulses Production Programme (A3P). Certain learnings from these programmes will assist in meeting the challenges and constraints regarding yield improvement and area expansion in the coming years.

6. Trends in Import of Pulses

Import of pulses in India grew at a rate of 9% during the 1980-81 to 2015-16 period but domestic supply grew only at 1.86% during the corresponding period. However, since 2016-17 India reduced its import dependence with value of imports declining from 4.2 billion dollars to 1.94 billion dollars in 2022-23 but it surged again in 2024-25..

Currently India is the largest importer of pulses accounting for 15-16% of total world imports, with imports touching 7.3 MT valued at approx Rs 42000 cr in 2024-25. The surge in imports in 2024-25 was on account of low domestic production and duty cuts on import of key pulses. The imports were led by a very high demand for yellow peas or Matar which had a share of 29% of the total import of pulses in 2024-25. Other pulses like chana and tur had a share of 22% and 17% respectively.

India has an inelastic demand for pulses, and import policies keep undergoing changes for protecting farmers and inflation control. Depending on the domestic supply situation there is switching between duty free regimes, heavy import tariffs or quantitative restrictions to prevent glut in the market. A poor agriculture year can lead to increase in price and shortage of supply with its impact on food inflation and global prices. Currently India relies mainly on Canada & Russia for yellow peas and lentils (masur); on Myanmar for urad; and on Australia for chick peas (chana). One of the issues highlighted by some experts

regarding imports is high degree of dependence on few exporting countries.

Achievement of Atmanirbharta Mission production goals will depend considerably on market scenario and Govt policy measures which will impact market behaviour and farmers' experiences, which in turn has a direct bearing on the sowing plans for next season.

7. Price Dynamics & Minimum Support Price (MSP)

Prices play an important role in decision making by farmers to grow pulses. Farmers need to be backed by procurement operations to encourage them to produce pulses without worrying about fall in market prices. Unlike other projects in the past, one of the most encouraging features of the Atmanirbharta Mission is assurance of remunerative prices and assured procurement of the three pulses at Minimum Support Price (MSP) by central agencies such as NAFED and NCCF. Moreover, substantial increase in MSP has taken place since 2014-15 to 2025-26 period. MSP of Arhar increased from Rs 4350 to Rs 8000; Urad from Rs 4350 to Rs 7800, and Masur from Rs 2950 to Rs 6425 which should make pulse cultivation attractive for farmers. It is notable that the growth in MSP of pulses has been higher than that of cereals.

However, for a seamless procurement experience, concerned agencies would need to address challenges which farmers face particularly related to registration, quality checks, payment issues, procurement infrastructure, and other logistical issues. Though procurement of pulses has generally been between 5-11% of production in the last few years, it remains to be seen to what extent farmers benefit from the assured procurement programme in the coming years.

8. Production and Technology Constraints

Pulses are often cultivated in marginal environment with low and erratic rainfall, poor soil, limited irrigation facilities, and are vulnerable to production risks. Pulse growers generally belong to poor or marginal farming community with limited access to technologies that are developed in Agricultural Institutes/State Agricultural Universities. Lack of awareness of latest pulse-production technologies is a critical gap leading to low productivity of pulses.

Compared to other countries the sector is lagging behind in adoption of improved technologies, and the benefits of cutting edge technologies, such as genomics, molecular marker assisted breeding, transgenics, molecular approaches for stress management, input use efficiency, and bio fortification do not reach all the pulse growing regions.

In many regions Varietal Replacement Rate(VRR) is not adequate, and high yielding varieties have not been widely adopted by farmers in the manner they were adopted for rice and wheat. Past experience shows that adoption of newer varieties especially under Tur and Black Gram has led to better resistance to diseases, pests and adverse climate.

Study by Indian Council for Agricultural Research (ICAR) - Indian Institute of Pulses Research (IIPR) shows that adoption of mechanisation can lead to 10 - 15% increase in productivity by improving efficiency and timely operations. Further, herbicide application plays an important role in weed control in pulse crop production system. Studies by IIPR have shown that average yield reduction due to weeds is about 37%. For the application of herbicides IIPR developed a Herbicide Applicator which can be operated by a single woman farm worker. Use of mechanised manual weeder with multiple attachments of blades for different sizes to cater to needs of weeding at different stages and types of pulses is also found very efficient for pulses instead of use of *Khurpi*.

Distribution of seed mini kits, and strengthening agri extension services in collaboration with KVKs, FPOs and Cooperatives can help in boosting production and provide better access to technology to farmers. In addition farmers need to be persuaded for adopting mechanisation of farm operations and ensure timely sowing, mechanised planting, and harvesting. For the plant and machinery needs of farmers to undertake mechanised ploughing, harvesting, threshing, and for setting up storage and processing facilities with a post harvest value chain for pulses, State Govts and Lead Banks can prepare district specific cluster level credit plans for banks to finance such activities.

Recognising all this, Atmanirbharta Mission has prioritised development and commercial availability

of climate-resilient, drought resistant / early maturing / short duration seed varieties, breeder seed production, timely weed control, mechanisation of operations, and use of good agronomic practices and herbicides. State specific interventions for intercropping will be crucial to expand the area as recommended in the Niti Aayog Report on pulses. For instance Soya Bean and Pigeon Pea in MP and Maharashtra; Pearl Millet and Pigeon Pea in Karnataka, AP and Gujarat; Sugarcane with Moong and Urad in UP, AP, Maharashtra & Karnataka.

9. Conclusion

Achieving self sufficiency in pulses promises to give significant economic benefits in the form of reduced import dependencies and better stability against global price fluctuations. Three major issues have persisted over the years in respect of production of pulses. First, the limited genetic potential for high yields, second, the vulnerability to pests and diseases, and third is the limited mechanisation especially for harvesting, post harvest, storage and processing. Vision-2050 document of ICAR-Indian Institute of Pulses Research (IIPR) based on a comprehensive assessment of past and present trends of factors that impact pulses sector, has succinctly envisioned many interventions for a science-led sustainable development of pulses.

The success of the Atmanirbharta Mission depends on how appropriate technologies are adopted by farmers, and biotic/abiotic stress management is tackled at the field level on a sustainable basis. The State Govt Departments, key agencies like KVK, ICAR institutes, FPOs, Cooperatives and the private sector, have a crucial role to play in achieving these stated goals. Besides, a careful balance between import restrictions and domestic production incentives by the Govt will remain a crucial factor in ensuring continued availability of pulses for desired level of consumption, as well as protection of domestic producers. One often thinks that better irrigation facilities can solve all production issues of pulses, but in its endeavour to achieve self sufficiency the Atmanirbharta Mission has given importance to combining increased irrigation with improved agronomic practices, Integrated Water Management, Integrated Weed

Management, and Integrated Nutrient Management. With India's unique agro climatic conditions and limited water availability, only a balanced approach can help in achieving sustainable and profitable pulse production. It is a mammoth task but Mission has some unique features like a higher outlay, long term objectives, assured 100% procurement, holistic implementation, setting up of processing units and monitoring of seed traceability which ought to assist the Govt agencies in achieving the Mission goals.

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AUTHORS' DETAILS:

**K. Vanitha*,
H. Rajashekara,
Babli Mog,
Bhagya, H.P.**

ICAR-Directorate of Cashew
Research,
Puttur – 574 202,
Karnataka

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Crop guardians: Inside the world of predatory ants in cashew and other crops

Ants are small but have big roles in ecosystems and farming. Besides killing crop pests, they help pollinate flowers, improve soil, and recycle nutrients. Ants are common, mobile, and aggressive generalist predators that quietly patrol crops and reduce pest numbers. Studies from cashew orchards in Karnataka to mango plantations in Australia show that ants can control many key pests, offering a low-cost, eco-friendly alternative to insecticides. Ant colonies can persist across seasons, thereby providing long duration protection to crops. It is interesting to note that weaver ants or red ants (*Oecophylla* spp.) alone prey on over 50 pest species. A 2022 meta-analysis across 17 crops found that ants lower the population of pests thereby reduce plant damage, and increase yields. Below are brief notes on ant predation strategies, examples of ant-pest interactions, and potential applications in pest management.

Prey-searching behavior in ants: Search patterns and movement strategies

Ants exhibit a remarkable diversity of prey-searching behaviours ranging from solitary, random walks to highly coordinated group hunts, which are supported by sensory integration, memory, and recruitment systems. Understanding these mechanisms helps in harnessing ants as biological control agents in agriculture.

a. Movement patterns:

Ant foragers employ different movement patterns depending on prey distribution and colony needs:

i. Random and systematic searching

When ants have no clues about where food might be, many of them wander around in random or almost-random ways to find new places. If an ant finds food, it is likely to come back to that same spot later, so their searching often changes from random wandering to going straight to places that worked before.

ii. Straight vs. winding paths

Ants that look for food that is rare and spread out tend to walk in straighter lines. That helps them cover more ground without going over the same places twice. Ants that hunt for food that is in groups or easy to find for eg., termites, move more slowly and follow winding, twisty routes so they can search carefully in one spot and catch more prey.

b. Foraging and Hunting Strategies:

i. Solitary and group hunting

Ground species often forage alone or recruit nestmates to retrieve large prey, while army ants and arboreal species conduct synchronized group raids.

ii. Specialized mandibles

Predatory ants have evolved distinct mouthparts like trap-jaw, snapping, or pitchfork mandibles for high-speed prey capture.



Mandibles of *Diacamma* sp., a species common in cashew plantations

iii. Chemical mimicry and venom

Specialized hunters use chemical signals, venoms to immobilize prey, or allomones to make rival colonies flee. Many species lay recruitment pheromones to guide nestmates to prey. For example, *Oecophylla* weaver ants use short-term pheromones to mobilize workers rapidly to large or mobile prey.

a. Other strategies:

- i. Tactile and vibrational cues: Ground-dwelling ponerine ants (e.g., *Platythyrea conradti*) rely on antennal contact and substrate vibrations to detect prey, especially in low-light conditions.
- ii. Spread-eagling and venom use: Spread-eagling refers to a cooperative hunting and defense tactic where multiple worker ants grab onto the limbs or body parts of a large prey insect or intruder and pull backward in opposite directions to stretch and sting to immobilize it. This cooperative strategy is particularly effective against large or agile insects.
- iii. Jumping and rapid strike: *Pachycondyla pachyderma* workers are sensitive to mobile prey, capturing them by jumping, seizing with large mandibles, and stinging before retrieval.

Ant species	Crop	Prey	Region
<i>Oecophylla longinoda</i>	Coconut	<i>Pseudothraupis wayi</i> , <i>Pseudothraupis devastans</i>	East Africa Ivory coast
	Cocoa	<i>Distantiella theobroma</i> , <i>caspids</i>	West Africa Ghana
	Coffee	<i>Antestiopsis intricata</i>	Ghana
<i>Oecophylla smaragdina</i>	Mango	<i>Selenothrips rubrocinctus</i> , <i>Cryptorrhynchus gravis</i>	Northern Australia Indonesia
	Citrus	<i>Rhynchocoris</i> spp.	China & Philippines
	Cashew	<i>Helopeltis antonii</i>	India
	Cocoa	<i>Helopeltis theobromae</i> , <i>Arablypelta theobromae</i> , <i>Pseudodoniella laensis</i>	Malaysia Papua New Guinea
	Oil palm	<i>Cernastopsyche pendula</i>	Malaysia
	Coconut	<i>Amblypelta cocophaga</i> , <i>Brontispa longissima</i>	Solomon Islands
<i>Dolichoderus thoracicus</i>	Cocoa	<i>Helopeltis antonii</i> , <i>H. theivora</i> <i>H. theobromae</i>	Indonesia Malaysia
<i>Formica</i> spp.	European forests	Many defoliators	Europe
<i>Anoplolepis longiceps</i>	Cocoa	<i>Pantorhytes</i> spp. <i>Pseudodoniella laensis</i>	Papua New Guinea
<i>Solenopsis geminata</i>	Multiple crops	Caterpillars, beetle larvae/pupae, fruit fly	Tropics/subtropics
<i>Crematogaster</i> sp.	Oil palm	<i>Leptopharsa gibbicarina</i>	Colombia
<i>Pheidole</i> spp.	Various field crops	Soil-dwelling pests, eggs, small larvae	Many parts of world.

- iv. Mandibular gland secretions: *Platythyrea conradti* produces volatile mandibular gland secretions that disorient termites and competing ants, causing them to roll onto their backs and become easy targets.
- v. Solitary dusk hunting: Some ponerines hunt alone at dusk, exploiting nocturnal insects and diurnal insects resting on foliage. Prey are captured rapidly, with stinging occurring almost immediately after contact.

	
<i>Tetraponera nitida</i> predating on egg of <i>Euthalia</i> sp.	<i>Oecophylla smaragdina</i> predating on <i>Deporaus marginatus</i> in cashew

Predatory ants and their pest targets: key examples

Published works have highlighted dominant predatory ant species of genus viz., *Oecophylla*, *Dolichoderus*, *Anoplolepis*, *Wasmannia*, and *Azteca* in the tropics, *Solenopsis* in the tropics and subtropics, and *Formica* in temperate environments. The table below summarizes a few well-documented ant-pest interactions.

Ants as predators of eggs of pests

Ant species	Eggs of pest	Crop
<i>Monomorium floricola</i>	<i>Opisina arenosella</i>	Coconut
<i>Solenopsis invicta</i>	<i>Heliothis virescens</i>	Cotton
<i>Tetramorium bicarinatum</i> , <i>Camponotus sericeus</i>	<i>Eldana saccharina</i>	Sugarcane
<i>Pheidole</i> sp.	<i>Chilo partellus</i>	Sorghum, maize

Observations on ant predation in cashew orchards at ICAR-DCR, Puttur, Karnataka:

Ant species	Pests
<i>Oecophylla smaragdina</i> (weaver ant)	Tea mosquito bug (<i>Helopeltis antonii</i>), <i>Deporaus marginatus</i> , caterpillars, bugs, beetles, moths etc
<i>Tetraponera nitida</i>	Eggs of butterflies eg. <i>Euthalia</i> sp.
<i>Tetraponera rufonigra</i> and undetermined ant species	Leaf miner (<i>Acrocercops syngamma</i>) larva.

Potential applications in pest management

Growing evidence from cashew, mango, teak, and other crops shows that using ants in pest management can be practical, profitable, and eco-friendly especially for small farmers and organic producers who want to cut chemical use while protecting crop quality. Ant-based biological control works well within integrated pest management (IPM) and organic farming.

Key uses include:

- Conservation biological control: Protect existing ant colonies by reducing broad-spectrum insecticide use and keeping hedgerows or shade trees that provide nesting sites.
- Augmentative releases: Adding or boosting ant colonies in orchards increases the chance they will find pests, especially when pests are unevenly distributed. Timing releases to match vulnerable pest stages (for example, early larval instars) improves control, because ants are more effective against mobile, soft-bodied prey. Moving ant colonies or pieces of nests into new orchards is already practiced in cashew and mango plantations in Australia and Papua New Guinea.

Where ants alone are insufficient for pest management, combining ant conservation with targeted, selective interventions can still reduce reliance on chemicals. As per a study in pomelo - orange orchards, ant-based control produced profits 15-47% higher than pesticide-only plots because input costs were lower, even though fruit yields were similar. However, it is important to note that some ants (notably *Solenopsis* fire ants) can also protect

honeydew-producing pests (aphids, scales, mealybugs) by deterring their natural enemies, which may offset benefits in certain contexts. Besides, some ant species feed on plants and may act as vectors of plant diseases, attack other beneficial insects etc.



Red ants tending aphids and mealybugs in cashew

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