SEPTEMBER 2026 |VOLUME 06| ISSUE 09

MSME Reg No:UDYAM-TN-05-0080141

AgriGate

(ISBN : 978-81-965582-9-1)

GROW WITH EVERY PAGE!

An International Multidisciplinary Monthly e-Magazine



From the Desk of Editor-in-chief

September 2026| Vol. 06 |Issue 09



I would like to introduce the launch of **"AgriGate - An International Multidisciplinary Monthly e-Magazine Volume 06 Issue No. 09 – September 2026"** with immense pleasure our team is privileged to dedicate this issue to the Agricultural Teachers and Scientists. Every year **Teachers' Day in India** is celebrated on birth anniversary of India's second President, **Dr. Sarvapalli Radhakrishnan**. On this day we appreciate and acknowledge the efforts of teachers in making responsible individuals. **World Rivers Day** (Theme-No Forests, No Rivers, No Water, No Life) is celebrated on the last Sunday of September. The day highlights the importance of rivers and generates awareness, and encourages people to improve and save water, rivers around the world.

The main objective of the magazine is to provide a publishing platform to young researchers and scientists as well as an information hub for the enthusiast, progressive farmer and also common readers. We envisage providing an online platform that appreciates illuminating articles on various topics related to agriculture and allied sciences monthly that will appraise and update the students, farming community and the whole society at large on the updates in agriculture.

Last but not the least, I wholeheartedly thank the editorial team, authors as well as anonymous reviewers for contributing to the release of this issue.

Our team welcomes your constructive feedback and suggestions to improve delivering fruitful content to hungry minds.



Dr R Shiv Ramakrishnan
Editor-in-chief
AgriGate Magazine

- AgriGate shall not take any responsibility for the contents of articles published in the magazine and all such responsibility shall lie with the author/s.
- The opinions expressed in the articles are solely of the author/s.
- Authors should also confirm that submitted manuscript is not under consideration for publication elsewhere (Simultaneous submissions).
- Once a manuscript is submitted for publication, it is considered that no part of the manuscript is copyrighted by any other nor is under review by any other publication.
- It is the sole responsibility of the author to obtain proper permission for the use of any copyrighted materials in the manuscript, prior to the submission of the manuscript.
- All the articles submitted for publication in AgriGate are reviewed for usefulness.
- Decision of the reviewers shall be final.
- Authors are solely responsible for originality of the published work.
- AgriGate shall not be liable to you or anyone else for any damages (including, without limitation, consequential, special, incidental, indirect, or similar damages)

Volume: 06 Issue No: 09

PRACTICAL UTILITY AND EFFECTIVE CONCENTRATIONS OF SALICYLIC ACID FOR ARID ZONE FRUIT PLANTS

Article ID: AG-VO6-I09-01

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture, Sri Karan Narendra Agriculture University (SKNAU), Jobner -303329, Rajasthan, India

Introduction

Salicylic acid (SA) is a naturally occurring phenolic compound that functions as a plant signaling molecule and plays an important role in regulating plant growth, development, and stress responses. Chemically, it is 2-hydroxybenzoic acid ($C_7H_6O_3$). In horticultural crops, salicylic acid is generally used in very low concentrations as a foliar spray, seed treatment, or sometimes as a root-zone treatment. It can improve the plant's ability to tolerate environmental stresses such as drought, salinity, high temperature, and oxidative stress, which are particularly important in arid and semi-arid regions.

Practical Uses of Salicylic Acid in Arid-Zone Fruit Plants

Arid-zone fruit crops such as **ber, pomegranate, date palm, aonla, bael, karonda, jamun, fig and citrus** frequently experience water scarcity, high temperature, salinity and hot dry winds. Salicylic acid can be useful as a plant biostimulant under these conditions.

Practical use	Expected effect
Drought-stress management	Improves plant tolerance to limited water availability and helps maintain physiological activity
Heat-stress tolerance	Supports antioxidant defense and protects cellular membranes
Salinity tolerance	Helps plants cope with salt-induced physiological and oxidative stress
Improved photosynthesis	Helps maintain chlorophyll and photosynthetic activity under stress
Better water-use	Can improve regulation of stomata and plant water status

Practical use efficiency	Expected effect
Reduction of oxidative damage	Stimulates antioxidant enzymes such as SOD, CAT and APX
Vegetative growth	May improve shoot growth, leaf development and overall plant vigor at suitable concentrations
Flowering and fruit set	May support reproductive development and reduce stress-related flower/fruit losses
Fruit retention	Can help maintain fruit development when environmental stress is severe
Fruit quality	May improve total soluble solids, sugars, phenolics, antioxidant properties and other quality attributes depending on crop and dose
Post-harvest quality	SA treatments may delay some physiological deterioration and extend storage life
Stress recovery	Helps plants recover after periods of drought, heat or other abiotic stress

Particularly useful in arid horticulture

1. Ber: Salicylic acid may be useful for improving tolerance to drought and high temperature and for maintaining growth, flowering and fruit development under stress.

2. Pomegranate: SA can support antioxidant defense, photosynthesis and fruit development, particularly when plants experience water or temperature stress.

3. Aonla: It may improve physiological performance and stress tolerance and can contribute to maintaining fruit quality.

4. Date palm: SA has potential for improving tolerance to salinity, drought and high-temperature conditions.

5. Bael, karonda and other arid fruits: Because these crops are often grown under moisture and temperature stress, SA can be considered as a supplementary stress-management treatment.

Importance of Salicylic Acid in Arid-Zone Fruit Plants

Salicylic acid (SA) is a naturally occurring phenolic plant growth regulator that acts as an important signaling molecule in plants. In arid and semi-arid regions, it is particularly useful

because fruit plants frequently experience **drought, high temperature, salinity, intense solar radiation and oxidative stress**.

Major importance

1. **Improves drought tolerance**
   i. Helps plants maintain better water status under limited irrigation.
   ii. Promotes physiological adjustments that reduce the adverse effects of water stress.
   iii. Particularly useful in drought-prone fruit crops such as **ber, pomegranate, aonla, date palm, bael, karonda and jamun**.
2. **Enhances photosynthesis**
   i. Helps maintain chlorophyll and photosynthetic activity during environmental stress.
   ii. Supports better functioning of leaves under high temperature and moisture deficit.
3. **Reduces oxidative stress**
   i. Drought, heat and salinity increase the production of reactive oxygen species (ROS).
   ii. SA stimulates antioxidant defense systems, helping protect cell membranes, proteins and photosynthetic machinery.
4. **Improves plant growth**
   i. At appropriate concentrations, SA can promote shoot and root growth, leaf development and overall plant vigor.
   ii. It may help plants recover more rapidly after drought or heat stress.
5. **Improves flowering and fruiting**
   i. SA can influence flowering, fruit set and reproductive development.
   ii. Better physiological condition of plants can contribute to improved fruit retention and yield.
6. **Reduces flower and fruit drop**
   i. Under heat and moisture stress, excessive flower and young-fruit abscission can occur.
   ii. Appropriate SA treatments may improve stress tolerance and consequently help maintain flowers and developing fruits.
7. **Improves fruit quality**
   i. SA may contribute to better accumulation of sugars, phenolic compounds, antioxidants and other quality-related constituents.

ii. It can also improve firmness and post-harvest behavior in some fruit crops.

8. **Improves salinity tolerance**
   i. In arid regions, irrigation with saline water and salt accumulation in soil are important problems.
   ii. SA can help plants regulate ion balance, maintain membrane stability and strengthen antioxidant defenses under salinity.
9. **Protects against high temperature**
   i. SA participates in stress-signaling mechanisms and can enhance the plant's ability to tolerate heat.
   ii. This is particularly relevant during hot summer conditions in Rajasthan and other arid areas.
10. **Improves nutrient-use efficiency**
   i. By maintaining root activity, membrane function and metabolic processes under stress, SA may improve the plant's ability to utilize available nutrients.

Importance of salicylic acid for arid-zone horticulture

Problem in arid areas	**Potential role of salicylic acid**
Drought	Improves water-stress tolerance
High temperature	Enhances heat-stress tolerance
Salinity	Improves physiological and antioxidant defense
Oxidative stress	Activates antioxidant mechanisms
Poor photosynthesis	Helps maintain chlorophyll and photosynthetic activity
Flower/fruit drop	Supports reproductive development under stress
Poor fruit quality	Can improve biochemical and physical quality attributes
Weak plant recovery	Promotes recovery following environmental stress

Effective Concentrations of Salicylic Acid for in Arid-Zone Fruit Plants

Salicylic acid (SA) is a plant signaling compound that can improve **drought tolerance, salinity tolerance, photosynthesis, antioxidant defense, flowering, fruit set, fruit retention and fruit quality**. The effective concentration depends on the fruit species, plant age, environmental stress and method of application.

Function	Effective concentration of SA	Application method	Typical timing
Seed treatment / nursery establishment	**0.05–0.5 mM** (≈ 7–69 mg/L)	Seed soaking/root treatment	Before sowing or transplanting
Improvement of seed germination and seedling growth	**0.1–0.5 mM**	Seed soaking or foliar spray	Early growth
Drought-stress tolerance	**0.5–1.0 mM** (≈ 69–138 mg/L)	Foliar spray	Before or during drought stress
Salinity tolerance	**0.25–1.0 mM**	Foliar spray/root application	Before and during salt stress
Improvement of photosynthesis and chlorophyll	**0.25–0.75 mM**	Foliar spray	Active vegetative growth
Antioxidant defense and reduction of oxidative stress	**0.25–1.0 mM**	Foliar spray	During heat/drought/salinity stress
Flowering and reproductive development	**0.1–0.5 mM**	Foliar spray	Pre-flowering
Fruit set and fruit retention	**0.1–0.5 mM**	Foliar spray	Flowering to early fruit set
Reduction of premature fruit drop	**0.25–0.5 mM**	Foliar spray	After fruit set
Fruit growth and yield improvement	**0.25–0.75 mM**	Foliar spray	Fruit-development stage
Improvement of fruit quality	**0.25–1.0 mM**	Foliar spray	Fruit development/ripening
Extension of post-harvest life	**0.5–2.0 mM**	Fruit dipping	After harvest

Approximate conversion:

1 mM salicylic acid ≈ **138 mg/L (ppm)**. Therefore, **0.5 mM ≈ 69 mg/L** and **0.25 mM ≈ 34.5 mg/L**.

Role of Salicylic Acid in Arid-Zone Fruit Plants in the National Economy

Salicylic acid (SA) is a naturally occurring plant signaling molecule that can improve plant tolerance to drought, salinity, heat and other stresses. These stresses are particularly important in arid and semi-arid fruit-growing regions. SA can help maintain photosynthesis, water balance, antioxidant defence and overall plant performance under stress.

Major economic roles

1. **Increases fruit productivity**

   SA can reduce the adverse effects of drought and other environmental stresses, helping fruit plants maintain growth, flowering, fruit set and yield.

2. **Improves fruit quality**

   Better photosynthetic activity, nutrient balance and antioxidant protection can contribute to improved fruit size, quality and market value. PGRs including SA can influence fruit set, yield, quality and fruit retention.

3. **Helps plants tolerate drought**

   SA improves water relations, osmotic adjustment and antioxidant activity, making it particularly useful where irrigation water is limited.

4. **Improves salinity tolerance**

   In arid regions, drought and salinity frequently occur together. SA can reduce oxidative damage and support physiological functions under salt stress.

5. **Reduces production losses**

   By reducing stress-induced damage, SA has potential to stabilize production during periods of heat, drought and salinity. This is economically important for fruit crops such as **ber, pomegranate, aonla, date palm and bael**, which are important arid-zone fruits in Rajasthan.

6. **Improves farmers' income**

   Higher and more stable yields and better fruit quality can increase the marketable produce and returns to growers.

7. **Supports sustainable water use**

   Improving plant performance under water stress can make limited irrigation more productive, although SA **does not replace irrigation** or good soil and water management.

8. **Strengthens the fruit-processing sector**

   Greater availability of quality fruits can support processing industries producing juices, beverages, dried fruits, jams, pulp and other value-added products.

9. **Generates rural employment**

   Improved fruit production increases employment in nursery production, orchard management, harvesting, grading, packaging, transportation, processing and marketing.

10. **Contributes to national food and nutritional security**

    Maintaining fruit production under harsh environmental conditions helps provide nutritious food while supporting the agricultural economy. Research reviews identify SA as a promising tool for improving horticultural crop resilience and productivity under abiotic stress.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article on Auxin.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

UTILIZATION AND EFFECTIVE CONCENTRATIONS OF INDOLE BUTYRIC ACID FOR ARID ZONE FRUIT PLANTS

Article ID: AG-VO6-I09-02

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture, Sri Karan Narendra Agriculture University (SKNAU), Jobner -303329, Rajasthan, India

Introduction

Indole-3-butyric acid (IBA): It is a synthetic auxin widely used in horticulture, particularly for vegetative propagation through cuttings. It promotes adventitious root formation and improves the establishment of propagated plants. In arid and semi-arid regions, where rapid establishment and a strong root system are especially important, IBA can be useful for several fruit crops.

Major uses of IBA

1. **Rooting of cuttings**
    i. IBA is primarily used to induce roots in stem cuttings.
    ii. It increases the percentage of rooted cuttings and promotes earlier root initiation.
    iii. It can improve the number and length of adventitious roots.
2. **Propagation of arid-zone fruit plants**

    IBA is particularly useful in propagation of:

    i. Ber (*Ziziphus mauritiana*)
    ii. Pomegranate (*Punica granatum*)
    iii. Fig (*Ficus carica*)
    iv. Grape (*Vitis vinifera*)
    v. Karonda (*Carissa carandas*)
    vi. Phalsa (*Grewia asiatica*)
    vii. Aonla (*Phyllanthus emblica*)
    viii. Guava (*Psidium guajava*)

3. **Improved establishment**

   Plants treated with an appropriate IBA concentration generally develop a better initial root system, helping transplanted plants establish more quickly under moisture-limited conditions.

4. **Nursery production**

   IBA is useful for producing uniform, well-rooted planting material. This is particularly valuable for commercial nurseries producing clonal or true-to-type plants.

5. **Root development under stress**

   A well-developed root system can improve access to available soil moisture and nutrients. Therefore, successful rooting with IBA may contribute indirectly to better establishment in arid environments.

Common methods of IBA application

Method	Typical IBA concentration*	Main use
Quick dip	500–5,000 ppm	Hardwood/semi-hardwood cuttings
Basal dip	100–2,000 ppm	Softwood and semi-hardwood cuttings
Extended soak	10–200 ppm	Rooting difficult cuttings
Rooting solution	Crop-dependent	Nursery propagation

*The optimum concentration varies greatly with fruit species, cultivar, cutting maturity, season and propagation conditions. Excessive IBA can inhibit rooting or injure the cutting.

Application in important arid-zone fruits plants

Ber: IBA can be used during vegetative propagation to promote adventitious rooting of suitable cuttings, although commercial ber production commonly relies on budding/grafting.

Pomegranate: IBA is widely useful for rooting hardwood cuttings and can improve rooting percentage and root development when the concentration is optimized for the cultivar and cutting type.

Fig: IBA treatment can improve rooting of hardwood cuttings and help produce vigorous nursery plants.

Karonda: IBA may be used to improve rooting of stem cuttings, particularly when natural rooting is slow.

Phalsa: Auxin treatment can enhance adventitious root formation and help obtain better rooted planting material.

Importance of Indole-3-Butyric Acid (IBA) Utilization in Arid Zone Fruit Plants to the National Economy

Indole-3-Butyric Acid (IBA) is an important synthetic auxin widely used in horticulture, particularly for root initiation, vegetative propagation, establishment of planting material, and improvement of plant growth. Its use is especially valuable in arid and semi-arid regions where water scarcity, high temperature, poor soils, and difficult plant establishment limit fruit production.

1. **Improvement in propagation**

IBA promotes rapid and uniform rooting of cuttings and is useful for multiplying difficult-to-root fruit plants. It can improve the production of quality planting material of arid-zone fruits such as ber, pomegranate, fig, karonda, jamun and other fruit crops.

2. **Reduction in nursery losses**

Better root formation results in stronger nursery plants with improved survival after transplantation. This reduces wastage of planting material and lowers nursery production costs.

3. **Better establishment under arid conditions**

Well-developed root systems help plants explore a larger volume of soil for water and nutrients. This is particularly important in arid areas, where limited soil moisture is a major constraint to fruit production.

4. **Increased fruit production**

Successful plant establishment and improved vegetative growth can contribute to better flowering, fruit retention and yield. Increased productivity per unit area can improve the income of fruit growers.

5. **Promotion of arid horticulture**

IBA-assisted propagation facilitates the rapid multiplication of economically valuable fruit crops suitable for dry regions. This supports the expansion of orchards, wasteland utilization and climate-resilient horticulture.

6. **Employment generation**

Increased fruit cultivation creates employment opportunities in nurseries, orchard establishment, irrigation, pruning, harvesting, grading, packaging, transportation and fruit processing.

7. **Reduction in dependence on imported planting material**

Efficient local multiplication of fruit plants can reduce dependence on costly planting material from distant production centres and strengthen domestic horticultural nurseries.

8. **Increased farmer income**

Higher plant survival, better orchard establishment and improved productivity can increase the profitability of fruit cultivation. This contributes to improved livelihoods of farmers in drought-prone regions.

9. **Development of fruit-based industries**

Greater availability of fruits provides raw material for juice, pulp, jam, jelly, dehydration, pickles and other processed products. Thus, IBA indirectly contributes to agro-processing and value addition.

10. **Efficient utilization of natural resources**

By helping plants develop effective root systems, IBA can support better utilization of available soil moisture and nutrients. This is particularly relevant to sustainable horticultural production in water-limited environments.

11. **Contribution to national food and nutritional security**

Expansion of fruit production increases the availability of vitamins, minerals, antioxidants and dietary fibre. Arid-zone fruit crops can therefore contribute to nutritional security while making productive use of marginal lands.

12. **Overall contribution to the national economy**

The economic importance of IBA is mainly indirect: it is a relatively small input that can improve the efficiency of propagation and orchard establishment. Better-quality planting material, higher plant survival, increased orchard productivity, employment generation and value addition together contribute to the growth of the horticultural sector and the national economy.

Effective Concentration of Indole-3-Butyric Acid (IBA) for Different Functions in Arid-Zone Fruit Plants

Indole-3-butyric acid (IBA) is a synthetic auxin widely used in fruit plant propagation, particularly for root induction in stem cuttings, rooting of difficult-to-root species, and establishment of nursery plants. The effective concentration depends on the plant species, type and maturity of cutting, method of application, and season.

Function / Purpose	Typical IBA concentration	Method of application	Suitable arid-zone fruit plants
Root initiation in softwood cuttings	500–1,000 ppm	Quick dip / basal treatment	Pomegranate, fig, karonda
Root initiation in semi-hardwood cuttings	1,000–2,000 ppm	Quick dip	Pomegranate, fig, karonda
Rooting of hardwood cuttings	2,000–4,000 ppm	Quick dip (5–10 sec)	Pomegranate, fig, ber
Rooting of difficult-to-root cuttings	3,000–5,000 ppm	Quick dip	Selected woody/arid fruit species
Rooting through rooting powder/formulation	0.2–0.8% IBA	Basal dipping/coating	Pomegranate, fig, karonda
Air layering / marcotting	1,000–3,000 ppm	Apply to girdled region	Fig, pomegranate and other suitable fruit plants
Improving root number and root length	500–2,000 ppm	Cutting treatment	Nursery fruit plants
Improving establishment of rooted cuttings	Low concentration, about 100–500 ppm	Root-zone treatment	Nursery-grown fruit plants

Important points

1. IBA is primarily a rooting hormone; its most established horticultural use is vegetative propagation rather than routine foliar spraying.
2. Higher concentrations are generally required for mature/hardwood cuttings, while soft, juvenile cuttings usually require lower concentrations.
3. For pomegranate, IBA around 1,000–3,000 ppm is commonly used for rooting cuttings, depending on cutting type and conditions.
4. For fig, approximately 1,000–2,000 ppm can be effective for rooting suitable cuttings.
5. Karonda and other difficult-to-root woody species may respond to concentrations toward the higher end of the range.

6. Excessive IBA can inhibit rooting, cause tissue injury or excessive callusing, so the concentration should be optimized for the particular cultivar and propagation method.
7. In arid Rajasthan conditions, successful rooting also depends strongly on humidity, rooting medium, irrigation, temperature and shade, not just IBA concentration.

Conversion:

1 ppm = 1 mg/L. Thus, 1,000 ppm IBA = 1 g IBA per litre of final solution.

Precautions

i. Use freshly prepared IBA solution or a properly formulated commercial rooting preparation.
ii. The basal portion of the cutting should receive the treatment; avoid excessive exposure.
iii. Concentration should be selected according to crop and cutting type.
iv. Maintain adequate humidity and a well-drained rooting medium.
v. Avoid waterlogging, because successful rooting requires adequate aeration.
vi. Always follow the label recommendation of the registered formulation when using a commercial IBA product.

Conclusion

IBA is an important plant growth regulator for the vegetative propagation and nursery production of arid- and semi-arid-zone fruit plants. Its most important function is stimulation of adventitious root formation, resulting in a higher proportion of successfully rooted cuttings and better-developed root systems. Its effectiveness depends strongly on the crop, cultivar, cutting maturity, concentration and method of application. IBA is an important plant growth regulator for arid-zone fruit production because it promotes rooting and successful establishment of fruit plants. Its appropriate utilization can reduce nursery losses, improve orchard establishment, increase productivity and farmer income, promote processing industries and generate rural employment. Consequently, IBA has considerable potential to support the development of profitable, resource-efficient and climate-resilient horticulture in arid and semi-arid regions of India.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article on Auxin.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

AI-DRIVEN SOIL SPECTROSCOPY: TRANSFORMING RAPID SOIL HEALTH ASSESSMENT

Article ID: AG-VO6-I09-03

Abishek P

1st M.Sc. (Ag.), Soil Science, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Introduction

Soil is often called the skin of the Earth, and like skin, it can be healthy or it can be sick. Roughly a third of the world's soils are already degraded by erosion, nutrient depletion, salinization, and compaction, and the pressure is only growing as farmers try to feed a global population racing past eight billion people. Every kilogram of grain, every liter of milk, and every basket of vegetables ultimately depends on a thin, living layer of soil that most of us never think about until it fails us.

Farmers and agronomists have always needed a way to answer a deceptively simple question: what is happening inside this soil right now? Traditionally, the answer required digging up a sample, packing it off to a laboratory, and waiting days or even weeks for results on nitrogen, phosphorus, potassium, organic carbon, and pH. By the time the report arrives, the growing season has often moved on. This lag between sampling and action has long been one of agriculture's quiet inefficiencies — and it is precisely the gap that a new generation of artificial intelligence-powered soil spectroscopy is closing.

Reading Soil With Light: The Science of Spectroscopy

Soil spectroscopy is built on an elegant physical principle: every mineral, organic molecule, and chemical bond in soil interacts with light in a characteristic way. When a beam of visible, near-infrared, or mid-infrared radiation strikes a soil sample, some wavelengths are absorbed by molecular bonds such as O–H, C–H, N–H, and C=O, while others are reflected back to a detector. The resulting reflectance curve — a spectral ‘fingerprint’ — encodes information

about organic matter, moisture, clay mineralogy, and more, without consuming any reagents or destroying the sample.

The catch is that this fingerprint is messy. Soil is a chaotic mixture of minerals, organic residues, water, and air, so absorption features overlap and interfere with one another in ways that defeat simple visual interpretation. For decades, scientists relied on classical statistical tools such as partial least squares regression (PLSR) to untangle these overlapping signals. These methods worked reasonably well, but they struggled with the nonlinear, high-dimensional nature of real-world spectral data collected across different soils, climates, and instruments.

The Spectral Toolbox

Researchers today draw on a family of complementary techniques, each suited to different soil properties and use cases, summarized below.

Technique	Spectral Range	What It Detects	Typical AI Model Used
Vis-NIR	350–2,500 nm	Organic matter, moisture, texture, iron oxides	PLSR, Random Forest, SVM
Mid-Infrared (MIR)	2,500–25,000 nm	Mineralogy, carbon fractions, functional groups	PLSR, Deep Neural Nets
Hyperspectral Imaging	400–2,500 nm (imaging)	Spatial nutrient maps (N, P, K)	CNNs, Gaussian Process Regression
Raman Spectroscopy	Laser-shift based	Mineral and molecular fingerprints	Ensemble ML, SVM
LIBS (Laser-Induced Breakdown)	UV–Vis emission lines	Elemental composition, heavy metals	Deep Learning, PLSR

Where Artificial Intelligence Changes the Game

This is where artificial intelligence enters the story, and where the field has accelerated dramatically over the past decade. A recent systematic review covering 155 studies published between 2014 and 2024 found that machine learning and deep learning models are now central to translating raw spectral data into usable soil nutrient predictions, with feature selection techniques helping models focus on the spectral bands that actually correlate with nitrogen, phosphorus, and potassium content rather than drowning in redundant noise (Springer Nature, Environmental Monitoring and Assessment, 2024).

Algorithms such as Random Forest, Support Vector Machines, Gaussian Process Regression, and increasingly Convolutional Neural Networks are trained on paired datasets — thousands of soil spectra matched against traditional wet-chemistry lab results — until the model learns to infer chemical properties directly from the shape of a reflectance curve. Once trained, that model can evaluate a brand-new soil sample's spectrum in a fraction of a second, effectively compressing a laboratory workflow that once took days into an instantaneous digital calculation.

A field-level study conducted across humid tropical and tropical agro-ecological zones in India illustrates the practical payoff. Researchers collected hyperspectral reflectance data spanning 350 to 2,500 nanometers from 159 soil samples and tested a suite of machine learning algorithms — including Support Vector Machine, Gaussian Process Regression, Random Forest, and Partial Least Squares Regression — to predict nitrogen, available phosphorus, and exchangeable potassium. The work was explicitly framed as a scalable alternative to conventional wet chemistry, aimed at closing the gap in timely soil health monitoring across diverse farming regions (Earth Systems and Environment, 2025).

Deep Learning and the Next Generation of Models

Where classical machine learning treats a spectrum as a long list of independent numbers, deep learning models such as convolutional neural networks (CNNs) are designed to recognize patterns across neighboring wavelengths, much as they recognize edges and shapes in a photograph. This matters because absorption features in soil spectra are not isolated points — they are broad, overlapping curves whose shape carries information. By learning these shapes directly from raw or lightly preprocessed spectra, deep networks can sometimes skip labor-intensive preprocessing steps that classical chemometrics required, such as manual baseline correction or scatter normalization.

The trade-off is data hunger: deep learning models typically need far larger training sets than PLSR or Random Forest to avoid overfitting. This is one reason the growth of open, shared soil spectral libraries — pooling tens of thousands of spectra from national and international soil surveys — has become just as important to progress in this field as the algorithms themselves. A model is only as good as the diversity of soils it has seen during training, and a library built entirely from temperate farmland will generalize poorly to tropical or arid soils unless it is deliberately expanded.

From the Laboratory Bench to the Open Field

Perhaps the most visible transformation is physical: spectrometers have shrunk from bulky benchtop instruments to handheld and even drone-mounted devices. A comprehensive review of emerging soil evaluation technologies highlights how visible–near-infrared and mid-infrared sensors are increasingly paired with Internet of Things (IoT) networks, enabling continuous, real-time monitoring of moisture, pH, and nutrient status directly in the field rather than back in a laboratory. The same review points to validated mobile-platform applications of AI-driven models that deliver real-time analysis of soil nutrients and physical characteristics, effectively putting a soil laboratory in a farmer's hand or on a drone's underside (MDPI Applied Sciences, 2026).

This mobility matters enormously for precision agriculture. Instead of a single composite soil sample representing an entire field, AI-enabled spectroscopy makes it economically feasible to scan dozens or hundreds of points across a farm, generating spatially explicit nutrient maps. Farmers and agronomic advisors can then vary fertilizer application rates zone by zone, rather than treating an entire field as uniform — reducing input costs, limiting nutrient runoff into waterways, and improving yields simultaneously.

Beyond Nutrients: Organic Carbon and Soil Structure

Soil organic matter and organic carbon are widely regarded as the single best indicators of overall soil health, influencing water retention, microbial activity, and long-term fertility. Evaluations of machine learning approaches using visible–near-infrared spectra have shown that these techniques can estimate soil organic matter and pH with useful accuracy, offering a rapid, non-destructive, and chemical-free alternative to conventional laboratory analysis. Because a single spectral scan captures information relevant to many properties simultaneously, one

measurement can, in principle, replace several separate laboratory assays (NCBI/PMC, Evaluation of Machine Learning Approaches to Predict SOM and pH).

Case in Point: Precision Nutrient Mapping in India

The India-based hyperspectral study mentioned earlier offers a useful window into what this looks like in practice. Working across two micro-watersheds representing distinct tropical agro-ecologies, the research team paired 159 field-collected soil samples with laboratory-measured nitrogen, phosphorus, and potassium values, then trained and compared four machine learning approaches on the same dataset. The explicit motivation was practical rather than purely academic: conventional wet-chemistry testing, while accurate, is too slow, too labor-intensive, and too costly to scale across the fragmented, smallholder-dominated farms typical of much of South Asia. A validated spectral-plus-ML pipeline offers a route to nutrient testing that smallholder farmers could plausibly access at meaningful scale, rather than a service reserved for large commercial operations with laboratory budgets.

Similar dynamics are playing out elsewhere. Reviews of soil-evaluation technology point to AI-driven models already validated on mobile platforms for real-time nutrient and physical-property analysis, while other research groups are fusing near-infrared spectroscopy with satellite and drone-based remote sensing so that a single farm visit, or even no farm visit at all, can generate a usable soil health snapshot. Each of these efforts is a variation on the same underlying idea: let sensors and algorithms do in seconds what a chemist's bench once needed days to accomplish.

Why This Matters: Speed, Cost, and Sustainability

- Turnaround time collapses from days or weeks to seconds or minutes, allowing decisions to be made within the same growing season rather than the next one.
- No hazardous reagents are consumed, reducing both cost and environmental burden compared with wet-chemistry digestion methods.
- A single spectral scan can simultaneously estimate multiple properties — organic carbon, nitrogen, texture, moisture — rather than requiring separate tests for each.
- Portable and drone-based sensors make dense, field-scale sampling economically realistic, supporting truly site-specific fertilizer and irrigation management.
- Continuous monitoring, rather than one-off snapshots, allows early detection of degradation trends such as declining organic matter or rising salinity.

A broader review of chemometrics, preprocessing, and machine learning in soil spectroscopy underscores that these gains are not merely incremental. It frames AI as fundamental to managing the heterogeneous, high-dimensional data that spectroscopy generates, and to interpreting complex spectra in ways that were simply impractical with earlier statistical tools — while also noting that model interpretability and the integration of very large datasets remain active areas of research (ScienceDirect, Soil Spectroscopy with Chemometrics, Machine Learning and Pre-Processing Techniques).



The Remaining Challenges

For all its promise, AI-driven soil spectroscopy is not a solved problem. Soil is extraordinarily variable across geography, climate, and land use, and a model trained on soils from one region often performs poorly when applied to a different one — a challenge researchers call the transferability or generalization problem. Building large, diverse, well-curated spectral libraries that pair spectra with reliable laboratory reference values remains expensive and logistically demanding. There is also the perennial 'black box' concern: deep learning models can be highly accurate yet difficult to interpret, which matters when farmers and regulators need to trust and explain the numbers behind a fertilizer recommendation.

Calibration transfer between different instrument brands and models, sensitivity to soil moisture and particle size at the moment of scanning, and the need for periodic recalibration against ground-truth laboratory data are all practical hurdles that current research continues to address, including through deep learning approaches that combine near-infrared spectroscopy with remote sensing data to improve robustness (Geoderma, On-site soil analysis: a novel approach combining NIR spectroscopy, remote sensing, and deep learning, 2024).

The Road Ahead

The trajectory is nonetheless clear. As spectral libraries grow larger and more geographically diverse, and as deep learning architectures become better at extracting robust features from noisy field spectra, the accuracy gap between spectroscopic prediction and traditional wet chemistry continues to narrow. Coupling spectroscopy with complementary data streams — satellite imagery, IoT soil sensors, weather records, and even soil eco-acoustic signals — promises even richer, more holistic pictures of soil health, moving the field from single-property prediction toward integrated soil health scoring.

For farmers, this technology offers something agriculture has rarely had: the ability to ask the soil a question and get a trustworthy answer before the next irrigation cycle, rather than after the harvest is already decided. For soil scientists and policymakers, it offers a path toward monitoring soil health at a scale — regional, national, even global — that was previously unimaginable with laboratory chemistry alone. In an era when sustainable, climate-resilient food production is not optional but essential, teaching machines to read the language of light reflected from a handful of soil may prove to be one of agriculture's quietly transformative achievements.

References

Jain, S., Sethia, D., & Tiwari, K. C. (2024). A critical systematic review on spectral-based soil nutrient prediction using machine learning. Environmental Monitoring and Assessment, 196(8). https://doi.org/10.1007/s10661-024-12817-6

Nenciu, F., Matache, M. G., Gageanu, I., Persu, I. C., Marin, F. B., & Voicea, I. F. (2026). Emerging Technologies for Soil Evaluation Using Spectrometry Sensing, Internet of Things and Machine Learning. Applied Sciences, 16(9), 4559. https://doi.org/10.3390/app16094559

Subramoniam, S. R., Naveena, K., Fasil, M., Chandrasekaran, B., Gopinath, G., Hebbar, R., & Surendran, U. (2025). Soil Spectra for Smart Farming—A Scalable Alternative to Wet Chemistry Using Fusion of Hyperspectral and Machine Learning in Diverse Agro Ecologies of India. Earth Systems and Environment, 10(5), 5665–5683. https://doi.org/10.1007/s41748-025-00886-7

Yang, M., Xu, D., Chen, S., Li, H., & Shi, Z. (2019). Evaluation of Machine Learning Approaches to Predict Soil Organic Matter and pH Using vis-NIR Spectra. Sensors, 19(2), 263. https://doi.org/10.3390/s19020263

Tang, Q., Cang, S., Jiao, J., Rong, W., Xu, H., Bi, K., Li, Q., & Liu, R. (2020). Integrated study of metabolomics and gut metabolic activity from ulcerative colitis to colorectal cancer: The combined action of disordered gut microbiota and linoleic acid metabolic pathway might fuel cancer. Journal of Chromatography A, 1629, 461503. https://doi.org/10.1016/j.chroma.2020.461503

Kok, M., Sarjant, S., Verweij, S.F.C., Vaessen, S.F.C., & Ros, G.H. (2024). On-site soil analysis: A novel approach combining NIR spectroscopy, remote sensing, and deep learning. Geoderma. https://doi.org/10.1016/j.geoderma.2024.116903

Volume: 06 Issue No: 09

COFFEE BERRY BORER UNDER A WARMING CLIMATE: IS HILL AGRICULTURE PREPARED?

Article ID: AG-VO6-I09-04

M. Senthil Kumar[1], M. Deivamani[2]*, P.Senthilkumar[3], M. Sankar[4], P.Ayyadurai[5] and V.K.Satya[6]

[1]Associate Professor (Agricultural Entomology), Horticultural Research Station, Yercaud, Tamil Nadu Agricultural University, Tamil Nadu, India

[2]Assistant Professor (Plant Pathology), Regional Research Station, Paiyur, Krishnagiri, Tamil Nadu Agricultural University, Tamil Nadu, India

[3]Associate Professor (Plant Nematology), Regional Research Station, Paiyur, Krishnagiri, Tamil Nadu Agricultural University, Tamil Nadu, India

[4]Libarian, Agricultural College and Research Institute, Vazhavachanur, Tamil Nadu Agricultural University, Tamil Nadu, India

[5]Assistant Professor (Agronomy), Centre of Excellence for Millets, Athiyandal, Tamil Nadu Agricultural University, Tamil Nadu, India

[6]Assistant Professor (Plant Pathology), Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirappalli, Tamil Nadu Agricultural University, Tamil Nadu, India

*Corresponding Author: M. Deivamani

Introduction

In the cool, shaded hills where coffee has long flourished, a tiny insect is emerging as a major test of the resilience of plantation agriculture. The coffee berry borer can enter a coffee berry almost unnoticed, reproduce inside it, and reduce bean quality long before visible crop loss becomes obvious. As hill climates become warmer and less predictable, the central question is whether coffee growers can shift from reacting to damage to anticipating it.

A Silent Threat in Green Hills

A coffee plantation in the hills can appear peaceful and productive: deep-green bushes growing under shade trees, mist moving across slopes, red and yellow cherries ripening at

different intervals, and farm workers beginning a harvest round. Yet, within this apparently healthy landscape, an insect smaller than a grain of rice can be quietly damaging one of the most valuable parts of the crop the coffee bean. The coffee berry borer, *Hypothenemus hampei*, is a tiny dark-coloured beetle that attacks coffee cherries by boring into the fruit and entering the seed-bearing portion. Once inside, it remains protected from weather, many natural enemies, and most external crop-protection measures. This hidden habit is what makes the pest especially dangerous. A farmer may see a healthy-looking coffee bush from a distance, but a proportion of its berries may already contain tunnels, eggs, larvae, pupae, or adult beetles. By harvest time, the damage may appear as reduced bean weight, poor quality, discoloured or broken beans, more defects during processing, and lower market value.



Figure 1. Coffee cultivation in hill regions depends on elevation, shade trees, humidity, rainfall, and field management. These same conditions can influence coffee berry borer activity.

In hill coffee areas, including the Shevaroy Hills of Tamil Nadu, the Nilgiris, Kodagu, Chikkamagaluru, Wayanad, Araku Valley, and other plantation landscapes, coffee production has always depended on a carefully balanced local climate. Elevation, cool temperatures, shade, rainfall pattern, soil moisture, flowering rhythm, berry development, and harvest timing influence the success of the crop. However, this balance is changing. Warmer daytime and night-time temperatures, irregular monsoon distribution, longer dry periods, sudden heavy rainfall, uneven flowering, and prolonged berry retention can alter the relationship between coffee plants

and their pests. Coffee berry borer is especially important because temperature, moisture, berry availability, altitude, and farm management together influence its survival, reproduction, movement, and infestation intensity. Studies have shown that climate, elevation, crop management, and berry production can jointly shape CBB incidence; in some coffee landscapes, warmer and more stable conditions, together with continuous berry availability, support longer periods of pest activity.

The Tiny Beetle That Damages the Bean



Figure 2. A small bore hole in a coffee berry can indicate coffee berry borer entry. The damaging stages remain largely hidden inside the fruit.

The coffee berry borer is among the most economically important insect pests of coffee worldwide. The adult female is tiny, dark brown to black, and typically only about 1.5–2.0 mm long. Despite its small size, it has a highly efficient survival strategy. The female beetle searches for a suitable coffee berry and enters it by making a minute hole, usually near the disc or navel end of the cherry. After boring through the outer fruit layers, it reaches the inner tissues and establishes itself inside the berry. The female lays eggs within this protected space, and the developing larvae feed on the seed tissue. Since the marketable coffee bean is the actual target, damage directly affects both productivity and quality.

The most obvious field symptom is a very small, circular bore hole on the berry surface. Sometimes fine powdery material can be seen near the entry point. In many cases, however, symptoms are missed because the hole is tiny, hidden under the berry disc, or located on the less

visible side of the fruit. When infested berries are split open, internal tunnelling and feeding damage may be observed. Depending on the timing and severity of infestation, berries may fall prematurely, beans may become lighter and poorly formed, and processed coffee may contain more insect-damaged beans. These defects can reduce bean grade, affect roasting performance, and lower the price received by farmers. CBB is particularly difficult to manage because the insect spends a major portion of its life within the berry. Once it has entered deeply, it becomes much less exposed to contact insecticides, fungal biocontrol agents, and natural enemies. This is why successful management depends heavily on detecting adult movement and preventing population build-up before the beetles become protected inside the fruit. The pest is widely recognized as one of the most destructive threats to coffee production because it damages both yield and market quality.

Warming Climate and Changing Pest Risk

For many coffee growers, higher elevation has traditionally offered some ecological protection. Cooler temperatures in hill regions can slow down insect growth and development, lengthen the time required to complete a generation, and restrict population multiplication during parts of the year. However, climate warming is steadily changing this advantage. When temperature rises, the coffee berry borer may develop more quickly, females may become active earlier or remain active longer, and more generations may be completed when suitable berries are available. This does not mean every warm year automatically produces a severe outbreak. Rather, it means the pest-risk calendar becomes more uncertain and more dependent on local conditions.

The relationship between climate and CBB is complex because temperature alone does not determine infestation. Coffee berry availability is equally important. If a plantation contains berries at different developmental stages for prolonged periods, or if ripe and dried berries remain after harvesting, the pest can find shelter and breeding sites for longer. Irregular rainfall and uneven flowering can increase this problem by producing berries over an extended time rather than within a synchronized crop cycle. In a well-managed plantation, farmers can reduce this advantage by timely harvesting, removing residual berries, maintaining sanitation, monitoring adult activity, and responding quickly to early signs of infestation. In a poorly managed plantation, the same climatic shift can magnify risk because the beetle finds a continuous supply of fruit and protected breeding sites.

Research has indicated that altitude, local climate, crop practices, and the availability of berries together shape CBB infestation. One recent analysis in Indonesian coffee systems found that infestation patterns varied across locations; where warm conditions remained relatively stable and berries were available continuously, the pest could persist throughout the year. Studies focused on climate change in Ethiopian coffee-growing regions have also projected that warmer conditions could increase the suitability of some landscapes for CBB proliferation and spread. For Indian hill agriculture, the practical message is clear: elevation should no longer be treated as a permanent guarantee of low pest pressure. Each estate must assess its own local microclimate, crop phenology, sanitation status, and pest history.

The Importance of Coffee Phenology

Coffee phenology the sequence of flowering, fruit set, berry growth, ripening, and harvest is central to coffee berry borer management. The insect cannot multiply without suitable berries. Therefore, the timing and uniformity of berry development determine when the pest can establish and how long it can remain in the plantation. Under stable seasonal conditions, flowering and berry development may be relatively synchronized, making it easier to predict pest risk and organize harvest operations. Under erratic rainfall and warmer conditions, flowering may occur in several flushes. This can result in a single coffee bush carrying flowers, immature berries, ripening cherries, and dried residual berries at the same time.

For CBB, such a plantation is highly favourable. Different berry stages provide a continuing sequence of resources. Adult females can move from old berries to newly suitable berries, and pest populations can bridge the period between one harvest and the next. A farmer may complete a main harvest but leave a small number of overripe, dried, or infested berries on branches or on the ground. These apparently insignificant berries may support beetle survival and produce the next infestation wave. This is why coffee berry borer management must be connected with crop phenology. A trap catch, field inspection, biological-control application, sanitation round, and harvest schedule should all be planned according to what is happening to berries in the field not merely according to a fixed calendar date.

A Hill-Plantation Example from Yercaud

Consider a coffee farm in the Shevaroy Hills near Yercaud, Tamil Nadu. The plantation has Arabica coffee grown under mixed shade trees. During a normal season, the grower expects the cooler hill conditions to reduce pest pressure. However, rainfall has been irregular, flowering

has occurred in more than one flush, and berries are developing unevenly. After the main picking, some ripe berries remain on branches, while dried berries from the previous season are still present in a few neglected patches. The farmer may not immediately consider this a serious risk, because the coffee bushes look vigorous and the plantation is located at elevation.



Figure 3. Alcohol-baited Broca traps help monitor adult coffee berry borer movement and can guide closer field inspection during high-risk periods.

Then a period of relatively warm weather follows intermittent rain. Adult female coffee berry borers begin moving in search of suitable berries. Because the beetles are very small, they are rarely noticed directly. Their initial entry holes are also difficult to see. If the farmer waits until widespread berry damage becomes visible, many beetles may already have entered the fruits and reproduced inside them. However, if a monitoring trap is placed in the plantation and checked regularly, it can provide a useful early warning. Increasing catches of adult borers do not automatically prove a serious infestation in every bush, but they signal that adult beetles are active in the plantation environment. The grower can then intensify berry inspection, check known hotspots, sample representative bushes, remove residual berries, and take timely biological or other locally recommended action.

This is where modern hill agriculture can become more prepared. A farm does not need to depend on a single high-cost technology. Even basic monitoring, record keeping, systematic sanitation, and farmer observation can substantially improve decision-making. Digital tools can strengthen this system further. A micro-weather station may record temperature, relative humidity, rainfall, and leaf-wetness conditions. A smart alcohol-baited trap may record adult catches. A mobile phone can capture geotagged photographs of infested berries, and an advisory

platform can combine weather, crop stage, previous infestation history, and trap catches to generate a risk alert. Instead of waiting for a visible outbreak, the farmer may receive a practical message: "Adult CBB activity is increasing; inspect berries this week, remove residual fruits, and consult local technical staff regarding biological-control timing."

Monitoring Is the First Line of Defence

Monitoring is not merely the act of placing a trap in the field. It is a process of observing the plantation carefully and using evidence to decide when to act. Alcohol-baited traps, commonly called Broca traps, attract adult female coffee berry borers that are flying in search of berries. These traps commonly use attractant blends containing ethanol and methanol. Trap catches provide information on adult movement and help identify periods when beetles may be colonizing new coffee fruits.

For monitoring to be useful, traps must be installed correctly, inspected at regular intervals, maintained properly, and linked with field scouting. Farmers should record the date, location, number of adult beetles captured, recent rainfall, crop stage, and any berry symptoms observed nearby. If trap catches rise, the next action should be a careful field check: examine berries from multiple bushes, especially from shaded, humid, poorly harvested, or historically infested areas. Look for entry holes and retain sample berries for confirmation where necessary.

Trapping should not be misunderstood as a complete cure. A trap alone cannot eliminate a large resident population already developing inside berries. Its greatest value is as a surveillance and decision-support tool. It tells the farmer when the pest is moving and where intensified inspection is needed. When monitoring is combined with sanitation, biocontrol, crop management, and coordinated action among neighbouring growers, it becomes a powerful component of integrated pest management.

Sanitation: Removing the Borer's Breeding Sites

Sanitation is the most fundamental and often the most economical component of coffee berry borer management. The basic principle is simple: remove the berries in which the pest survives and reproduces. Yet, carrying out sanitation well requires discipline and consistency. Coffee growers should avoid leaving ripe, overripe, dried, damaged, and infested berries on branches after harvest. Fallen berries should also be collected from the ground, especially beneath bushes with known infestation. These berries can harbour eggs, larvae, pupae, and adults, serving as hidden reservoirs for the next season.

A clean plantation interrupts the pest's life cycle. A neglected plantation extends it. This difference is particularly important under warming conditions, when survival between crop cycles may improve and adult activity may continue for longer periods. Proper sanitation must therefore be treated not as a once-a-year event but as a repeated farm operation. It should begin during harvesting, continue immediately after the main harvest, and include follow-up rounds to remove missed berries.



Figure 4. Thorough harvesting and post-harvest removal of berries remaining on plants and soil reduce sites where coffee berry borer can survive and multiply.

Local technical recommendations should guide the safe destruction of infested fruits. Kerala Agricultural University guidance emphasizes proper crop hygiene, timely harvest, field sanitation, appropriate shade and drainage, and proper processing practices. It also recommends collecting infested berries and boiling them for 2–3 minutes to kill pest stages before disposal, where applicable under extension guidance. Farmers should avoid transporting infested berries between plantations or leaving them in waste heaps where adult beetles can emerge

Biocontrol and the Role of Beauveria bassiana

Biological control offers an important opportunity to reduce dependence on indiscriminate chemical use in coffee. The entomopathogenic fungus *Beauveria bassiana* is one of the best-known biological agents used against coffee berry borer. Its spores can adhere to the insect's body, germinate under suitable conditions, penetrate the insect cuticle, grow inside the body, and eventually kill the beetle. The fungus is particularly useful when adult females are exposed outside the berry, such as during movement, flight, or early colonization of fruits.

However, *Beauveria bassiana* should be viewed as part of a larger system rather than as a stand-alone replacement for all other practices. Its success depends on using a good-quality, viable product; applying it at an appropriate time; obtaining adequate coverage of the target surfaces; and ensuring that local weather conditions favour fungal infection. Relative humidity, rainfall, sunlight exposure, application method, and compatibility with other pesticides can influence performance. If the fungus is applied when most beetles are already deep inside berries, its effect may be reduced. If it is used when adult females are active and exposed, and is supported by sanitation and monitoring, it can contribute meaningfully to population suppression.

Field studies on sustainable CBB management have shown that integrated systems combining cultural management, monitoring, biological control, and *B. bassiana* can reduce infestation while reducing reliance on conventional insecticide use. In Araku coffee areas, reports have also described the use of biopesticides and traps as part of efforts to protect coffee against berry borer.

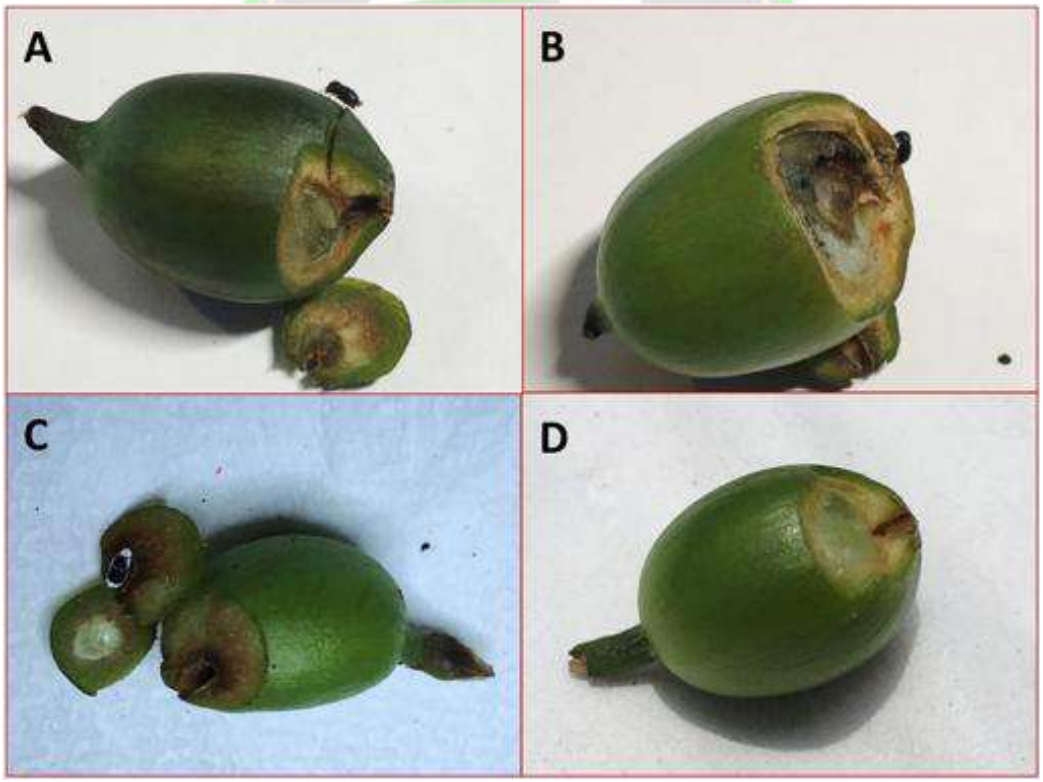


Figure 5. The entomopathogenic fungus* Beauveria bassiana *can infect coffee berry borer adults and is most effective when integrated with monitoring and sanitation.

What Farmers Can Do Now

Farmer Action Box: Five Steps for Climate-Smart Coffee Berry Borer Management

1. Monitor adult beetle activity and inspect berries regularly. Install recommended alcohol-baited Broca traps in representative blocks, check them at regular intervals, and maintain a simple record of trap catches, rainfall, crop stage, and infestation symptoms. When catches increase, inspect representative bushes immediately for entry holes and infested berries.

2. Complete harvesting and avoid leaving residual fruits. Pick mature, overripe, dried, and visibly infested berries from all bushes. Collect fallen fruits from the ground. Revisit the plantation after the main harvest to remove berries missed during picking.

3. Destroy infested berries safely. Follow local Coffee Board, TNAU, KAU, or state agriculture-department recommendations for handling infested berries. Do not leave them in piles or move them to other areas without treatment. Where technically recommended, hot-water treatment can kill CBB stages inside the collected berries.

4. Use *Beauveria bassiana* only as part of a planned IPM programme. Select an authorized, quality-assured product and seek expert advice on timing, formulation, dose, application method, weather conditions, and compatibility with other crop-protection inputs. Apply when adult beetles are likely to be exposed outside berries.

5. Treat pest management as a community task. Coordinate monitoring and sanitation with neighbouring coffee growers. One poorly managed plantation with old berries, abandoned bushes, or infested waste can become a source of reinfestation for nearby farms.

The Future: Climate-Smart Digital IPM

Hill agriculture is not unprepared by definition. It becomes prepared when farmer observation, field sanitation, biological control, weather awareness, and digital technology are combined into a practical decision system. The future of coffee berry borer management will not be based on finding one "perfect" spray or trap. It will be based on improving the timing of every action.

A climate-smart IPM programme can integrate micro-weather monitoring, coffee phenology records, alcohol-trap catches, berry sampling, field sanitation, *Beauveria bassiana* application, and farmer advisories. In the coming years, AI-supported systems may help analyse local temperature, humidity, rainfall, elevation, crop stage, trap counts, and historical pest records to estimate when infestation risk is likely to increase. Smart traps

equipped with cameras and automated counters may send pest data directly to a mobile dashboard. Farmers may receive risk alerts in Tamil or other local languages. Extension workers may map hotspots using GPS-tagged field observations and organize collective sanitation campaigns before pest populations disperse.

The most important principle remains simple: do not wait until the coffee berry borer has become safely hidden inside the fruit. Monitor adult movement, inspect berries carefully, remove pest reservoirs, use biocontrol at the right time, and make decisions based on field evidence. Under a warming climate, hill-coffee farmers will need to act earlier, monitor more systematically, and work more collectively.

The future of coffee protection in India's hills lies in combining traditional plantation care with climate-informed, technology-supported integrated pest management before a tiny beetle turns a promising coffee berry into a hidden source of loss.

References

Johnson, M. A., Ruiz-Diaz, C. P., & Manoukis, N. C. (2020). Coffee berry borer (*Hypothenemus hampei*), a global pest of coffee: A review of management strategies and potential for future research. *Insects, 11*(12), 882. https://doi.org/10.3390/insects11120882

Aristizábal, L. F., Johnson, M. A., Shriner, S., Hollingsworth, R. G., Manoukis, N. C., Myers, R., Bayman, P., & Arthurs, S. P. (2016). Integrated pest management of coffee berry borer: Strategies from Latin America. *Insects, 7*(3), 43. https://doi.org/10.3390/insects7030043

Jaramillo, J., Chabi-Olaye, A., Kamonjo, C., Jaramillo, A., Vega, F. E., Poehling, H.-M., & Borgemeister, C. (2009). Thermal tolerance of the coffee berry borer *Hypothenemus hampei*: Predictions of climate change impact on a tropical agricultural pest. *PLoS ONE, 4*(8), e6487. https://doi.org/10.1371/journal.pone.0006487

Volume: 06 Issue No: 09

CHLORELLA AS A FOOD & FUEL: THE CHALLENGES

Article ID: AG-VO6-I09-05

***Jegatheeswaran, M., Sukumar, V., Prabhu, G. and Berliner, J.**

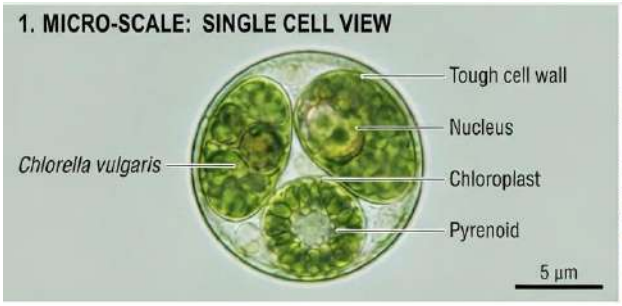
ICAR- National Research Centre for Banana, Tiruchirappalli, Tamil Nadu, India

*Corresponding Author: Jegatheeswaran, M

Introduction

The global search for sustainability and nutrient-dense foods has brought microscopic algae, known as microalgae, into the mainstream wellness spotlight. Among these, Chlorella is a green, unicellular, and non-motile microalga in size ranging from 2 to 10 micrometers. It has emerged as a remarkable biological candidate. Thriving in diverse aquatic habitats spanning both freshwater and marine environments, the genus Chlorella encompasses over ten recognized species, with Chlorella vulgaris standing out as the most widely studied and commercialized.

Initially evaluated as an alternative protein source to combat global malnutrition, Chlorella is now celebrated across multiple sectors. Beyond human and animal nutrition, its exceptional environmental adaptability allows it to be cultured on a large scale for wastewater remediation, cosmetic formulations, and biofuel development.





Nutritional Profiles: Proteins, Lipids, and Powerful Antioxidants

Chlorella acts as a miniature nutritional factory, packing a dense concentration of macronutrients such as proteins, lipids, and carbohydrates. It is also packed with antioxidants into every single cell.

High-Quality Protein Content

One of the important characteristics of chlorella is its remarkable protein richness, which typically accounts for 43% to 58% of its dry weight depending on the strain and cultivation conditions. Crucially, it provides a complete amino acid profile, meaning it contains all essential amino acids that human bodies cannot synthesize on their own. This makes it a valuable plant-based protein alternative for vegetarians and athletes alike.

Lipid Production and Heart-Healthy Fats

While Chlorella naturally accumulates moderate levels of lipids roughly 5% to 30% of its dry weight under normal conditions, targeted environmental stressors such as nitrogen or phosphorus deprivation can shift its metabolism to dramatically elevate lipid yields. Although this high lipid content makes it a prime candidate for renewable biodiesel research, these fats are equally valuable in nutrition. They are rich in polyunsaturated fatty acids (PUFAs), including heart-healthy omega-3 and omega-6 fatty acids that support cardiovascular wellness and help maintain health in humans.

Cellular Protection via Antioxidants

Beyond macro and micronutrients, Chlorella is loaded with natural antioxidants such as chlorophyll, β-carotene, lutein, and phycocyanin. Earlier studies demonstrated that these compounds protect human and animal cells from reactive oxygen species (ROS), while simultaneously strengthening immune function and reducing chronic inflammation markers.

Practical Applications for Humans and Animals

Chlorella's high nutritional and biochemical content makes it a versatile resource for various applications, including human dietary supplements, cattle feed, and aquaculture.

Human Dietary Supplements: Chlorella is most commonly found as fine powder, capsules, or tablets for human dietary usage. These powders and capsules can be used to make food and beverages such as juice and smoothies. It serves as an exceptional natural source of micronutrients including provitamin A, iron, magnesium, zinc, and vitamin B12. Regular consumers often take it for natural heavy metal detoxification, immune support, and sustained daily vitality.

Animal Feed and Aquaculture: In cattle management and aquaculture, Chlorella biomass is used as a high-protein feed additive. It enhances growth rates, improves natural pigmentation in farmed fish and poultry due to its high carotenoid content, and strengthens disease resistance in

livestock. Similarly, in the ornamental aquarium hobby, Chlorella is valued for enhancing the natural coloration and overall vitality of fish, serving as a beneficial nutritional supplement that supports their immune system (Ahmad et al., 2018).

Chlorella as Biofuel

The ability of chlorella to produce biofuel is mainly associated with its ability to accumulate lipids that can be converted into biofuel. Under specific cultivation conditions or stress conditions chlorella can change its metabolism towards lipid storage. The accumulated lipids can be isolated from the biomass of chlorella and converted into fatty acid methyl esters (FAME) which can be used as biodiesel. Production of biofuel from chlorella includes several stages of processes including biomass cultivation, harvesting and lipid extraction are the important processes because the algal cells are microscopic and contain high water content. Effective methods such as centrifugation, filtration, and solvent extraction are used to get improved biomass recovery and lipid yield.

Composition of lipids will impact the quality of biodiesel. Fatty acids such as palmitic, oleic, and linoleic acids may influence the fuel properties. The amount of saturated and unsaturated fatty acids affects the characteristics of the fuel such as oxidation stability, viscosity, and cold flow properties. Growing the chlorella in a controlled environment can help not only to produce lipids but also for obtaining suitable biodiesel quality. After lipid extraction from chlorella the remaining biomass can be utilized to produce other byproducts including biogas, Fertilizers, or other bio based compounds.

Industrial Production Hurdles and Natural Drawbacks

Despite chlorella's immense health potential, transitioning it from laboratory flasks to mass commercial food markets comes with significant technical and economic challenges:

High Production Costs: Cultivation of chlorella biomass in high volume needs high initial investment because it needs a controlled environment and suitable nutrient medium. It also needs well trained professionals which makes the production cost high.

Contamination Risks and Biosorption: Chlorella is efficient in absorbing heavy metals and toxins from its environment. If chlorella was cultivated in unmonitored open ponds or wastewater systems, it can accumulate heavy metals or toxins in its cells, so cultivation of chlorella requires rigorous quality control before it is deemed safe for human consumption.

Digestibility and Sensory Hurdles: Chlorella consist of extremely tough, indigestible cell wall made of cellulose, requiring mechanical processing to make its nutrients accessible to the human digestive tract. Furthermore, it carries a strong, earthy, grassy flavor and deep green color that can prevent everyday consumers from intake.

Market Comparison and Future Research Directions

When Chlorella is stacked against commercial food supplements such as whey protein isolates, synthetic multivitamins, or its saltwater cousin Spirulina, Chlorella holds a unique space. While Spirulina often wins on lower production costs and slightly higher raw protein percentages than Chlorella, it typically has superior concentrations of heart-healthy omega-3 fats, provitamin A, iron, and magnesium.

However, synthetic supplements and isolated whey proteins still dominate grocery shelves due to their lower price points, standardized dosing, and more pleasant consumer formats. To successfully bridge the gap and replace conventional market supplements, future research and development in microalgal biotechnology must focus heavily on optimizing low-cost, scalable photobioreactor designs to minimize contamination risks and drastically lower media input costs, utilizing genetic and metabolic strain engineering to maximize targeted protein and omega-3 yields naturally, and advancing food processing techniques to mask undesirable flavors and create consumer-friendly delivery formats, ultimately positioning Chlorella as a cost-effective, sustainable pillar of the future human diet and animal feed.

References

Ahmad, M. T., Shariff, M., Yusoff, F. M., Goh, Y. M., & Banerjee, S. (2018). Applications of microalga *Chlorella vulgaris* in aquaculture. *Reviews in Aquaculture, 1*(1), 1–19.

Griffiths, M. J., & Harrison, S. T. L. (2009). Lipid productivity as a key characteristic for choosing algal species for biodiesel production. Journal of Applied Phycology, 21(5), 493–507. https://doi.org/10.1007/s10811-008-9392-7.

Lee, J. H., Kim, Y. H., & Kim, J. D. (2017). Antioxidant and growth-promoting effects of Chlorella vulgaris extract in insect cell cultures. Applied Microbiology and Biotechnology, 101(14), 5705–5713. https://doi.org/10.1007/s00253-017-8294-5.

Oh, Y.-K., Kim, S., Ilhamsyah, D. P. A., Lee, S.-G., & Kim, J. R. (2022). Cell disruption and lipid extraction from Chlorella species for biorefinery applications: Recent advances. Bioresource Technology, 360, 128183. https://doi.org/10.1016/j.biortech.2022.128183.

Ru, I. T. K., Sung, Y. Y., Jusoh, M., Wahid, M. E. A., & Nagappan, T. (2020). *Chlorella vulgaris*: a perspective on its potential for combining high biomass with high value bioproducts. *Applied Phycology*, *1*(1), 2–11. https://doi.org/10.1080/26388081.2020.1715256

Volume: 06 Issue No: 09

CULTIVATION AND BENEFIT OF JAMUN IN RAJASTHAN

Article ID: AG-VO6-I09-06

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture, Sri Karan Narendra Agriculture University (SKNAU), Jobner -303329, Rajasthan, India

Introduction

Jamun (*Syzygium cumini*), also known as Indian blackberry or Java plum, is an important fruit crop valued for its nutritional, medicinal, and economic importance. It is a hardy, drought-tolerant tree that can be successfully cultivated in many parts of Rajasthan, particularly in regions with moderate rainfall and access to irrigation. Improved varieties such as **Goma Priyanka** have also been adopted in Rajasthan because of their high yield, small stature, and suitability for high-density planting.

Climate

- Jamun grows well in tropical and subtropical climates.
- It tolerates high summer temperatures (up to 45°C) after establishment.
- Young plants require protection from severe frost.
- Annual rainfall of **600–1,000 mm** is ideal, though irrigation can compensate in drier areas. Krishikosh

Suitable Areas in Rajasthan

Jamun cultivation is suitable in:

- Udaipur Kota Bundi Chittorgarh Bhilwara Banswara
- Dungarpur Sirohi Jaipur (with irrigation) Ajmer and other irrigated regions

Soil Requirements

- Deep, fertile, well-drained loam or clay loam soils are ideal.
- Soil pH: **6.5–8.0**
- The crop tolerates slightly saline and alkaline soils better than many fruit crops.

Recommended Varieties

- **Goma Priyanka** – High yielding, 85–90% pulp, small seed, regular bearer, suitable for semi-arid regions and high-density planting. Indian Council of Agricultural Research
- Goma Priyanka II
- Thar Kranti
- Local seedling selections

Propagation

- Softwood grafting Patch budding
- Veneer grafting Air layering (less common)

Vegetative propagation is preferred because plants bear earlier and produce uniform fruits. IJPST

Planting

- **Best planting time:** July–August (monsoon)
- **Pit size:** 1 m × 1 m × 1 m
- **Fill pits with**:
  - 20–25 kg well-decomposed FYM
  - 1 kg single super phosphate
  - 100 g insecticide (if needed)

Spacing

- Normal planting: **8 × 8 m**
- High-density planting (dwarf varieties): **5 × 5 m** or closer with canopy management.

Irrigation

- Water immediately after planting.
- Irrigate every 7–10 days during summer for young plants.
- Mature trees need irrigation mainly during flowering and fruit development.
- Drip irrigation is recommended for water conservation.

Nutrient Management

Apply annually:

- FYM: 20–50 kg/tree (depending on age)
- Nitrogen: 500–1,000 g/tree
- Phosphorus: 250–500 g/tree
- Potash: 250–500 g/tree

Split nitrogen into two doses:

- Before flowering After fruit set

Weed Management

- Keep the basin weed-free.
- Apply organic mulch to conserve moisture and suppress weeds.
- Intercropping with legumes during the initial years is beneficial.

Training and Pruning

- Develop a strong framework during the first 3–4 years.
- Remove diseased, dead, and crossing branches annually.
- Minimal pruning is generally required.

Flowering and Fruiting

- Flowering: March–April
- Fruit maturity: June–July
- Grafted plants start bearing in **4–5 years**.
- Seedling plants may take **8–10 years** to bear.

Pest and Disease Management

Major pests:

- Leaf-eating caterpillar Scale insects Whiteflies

Diseases:

- Leaf spot Anthracnose

Management:

- Orchard sanitation
- Regular monitoring
- Recommended insecticides and fungicides when infestation exceeds economic threshold levels.

Yield

- Grafted trees: **50–70 kg fruits/tree/year**
- Mature seedling trees: **80–100 kg fruits/tree/year** under good management.

Harvesting

- Harvest when fruits turn deep purple or black.
- Pick fruits carefully to avoid bruising.

- Fruits should be marketed quickly because of their short shelf life.

Advantages of Jamun Cultivation in Rajasthan

- Suitable for semi-arid conditions.
- Drought tolerant after establishment.
- Low maintenance compared to many fruit crops.
- High medicinal and nutritional value.
- Good market demand for fresh fruits and processed products (juice, squash, vinegar, jam, and seed powder).
- Can be grown in orchards, on farm boundaries, and in agroforestry systems.

Importance of Jamun Cultivation

Jamun (*Syzygium cumini*), also known as Indian blackberry or Java plum, is an important indigenous fruit crop of India. It is highly valued for its nutritional, medicinal, and economic benefits. Jamun cultivation is gaining popularity because of its adaptability to diverse climatic conditions and increasing market demand.

1. High Nutritional Value

- Jamun fruits are rich in vitamins (especially vitamin C), iron, calcium, phosphorus, antioxidants, and dietary fiber.
- The fruits help improve immunity and overall health.

2. Medicinal Importance

- Jamun is widely used in Ayurvedic, Unani, and traditional medicine.
- The seeds are known for their anti-diabetic properties and are used in herbal formulations.
- Fruits, bark, leaves, and seeds possess antimicrobial, anti-inflammatory, and antioxidant properties.

3. Suitable for Diverse Agro-Climatic Conditions

- Jamun thrives in tropical and subtropical climates.
- It tolerates drought, waterlogging, and saline soils better than many other fruit crops.
- It performs well in arid and semi-arid regions with proper irrigation during establishment.

4. Low Maintenance Crop

- Once established, Jamun trees require relatively less irrigation, fertilizers, and plant protection measures.

- The crop is hardy and has fewer pest and disease problems.

5. Long Productive Life

- Jamun trees are perennial and can remain productive for 50–60 years or more.
- This ensures a stable and long-term income for farmers.

6. Economic Benefits

- Fresh fruits fetch good market prices during the summer season.
- Value-added products such as juice, squash, jam, jelly, vinegar, wine, and seed powder increase farmers' income.
- Growing demand from pharmaceutical and food processing industries enhances profitability.

7. Environmental Benefits

- Jamun trees help in soil conservation and reduce erosion.
- They provide shade, improve biodiversity, and contribute to carbon sequestration.
- The trees are suitable for agroforestry and avenue plantation.

8. Employment Generation

- Jamun cultivation creates employment in nursery raising, orchard management, harvesting, processing, packaging, and marketing.
- Processing industries also generate rural employment opportunities.

9. Export Potential

- Jamun and its processed products have growing demand in international markets due to their health benefits.
- Proper post-harvest handling and processing can enhance export opportunities.

10. Climate Resilience

- Jamun is tolerant to high temperatures and adverse weather conditions.
- It is considered a climate-resilient fruit crop suitable for sustainable horticulture.

Fruit Quality of Jamun:

1. Physical Characteristics

- **Fruit shape:** Oblong, oval, or round.
- **Fruit size:** 2–4 cm long and 1–2 cm in diameter, depending on the variety.
- **Fruit weight:** Generally 5–20 g per fruit.

- **Skin colour:** Changes from green to pink, red, and finally deep purple or black when fully ripe.
- **Pulp:** Soft, juicy, purple-white, and succulent.
- **Seed:** Usually one seed, though some varieties are nearly seedless.

2. Chemical Characteristics

- **Total Soluble Solids (TSS):** 12–18 °Brix.
- **Acidity:** 0.4–0.9%.
- **Total sugars:** 8–15%.
- **Reducing sugars:** 4–8%.
- **Vitamin C:** Approximately 15–30 mg per 100 g of pulp.
- **pH:** 3.5–4.5.

3. Nutritional Quality

Jamun fruits are rich in:

- Carbohydrates Dietary fibre Calcium Phosphorus Iron Potassium
- Vitamin C Anthocyanins and other antioxidants Phenolic compounds and flavonoids

4. Sensory Quality

- Pleasant sweet to mildly acidic taste with slight astringency.
- Distinctive aroma and flavour.
- Juicy pulp with good eating quality.
- Attractive dark purple to black colour, preferred by consumers.

5. Processing Quality

Jamun is suitable for processing into:

- Juice Squash Nectar Jam Jelly Wine
- Vinegar Syrup Ice cream and other beverages

Good processing varieties have:

- High pulp percentage (75–85%)
- High TSS
- Attractive purple colour
- Rich flavour
- Low seed percentage

6. Medicinal Quality

- Rich in antioxidants that help reduce oxidative stress.
- Seeds contain **jamboline** and **ellagic acid**, traditionally associated with blood sugar management.
- Fruit exhibits antidiabetic, antimicrobial, anti-inflammatory, and cardioprotective properties.
- Helps improve digestion and supports immune health.

Characteristics of High-Quality Jamun Fruits

- Uniform dark purple or black colour
- Large fruit size
- High pulp-to-seed ratio
- Sweet taste with mild acidity
- High TSS (≥15 °Brix)
- Rich in anthocyanins and vitamin C
- Free from cracks, bruises, insect damage, and diseases

Conclusion

Jamun cultivation is an economically viable, environmentally sustainable, and nutritionally important horticultural enterprise. Its hardy nature, low cultivation cost, long productive life, and increasing demand for fresh and processed products make it an excellent fruit crop for farmers, particularly in regions like Rajasthan where hardy fruit species are preferred.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

THE NEXT INVASIVE PEST COULD BE AT OUR DOORSTEP: WHY EARLY DETECTION MATTERS

Article ID: AG-VO6-I09-07

M. Senthil Kumar[1], M. Deivamani[2]*, P.Senthilkumar[3], K.Sasikumar[4], K.Govindan[5] and S.Malathi[5]

[1]Associate Professor (Agricultural Entomology), Horticultural Research Station, Yercaud, Tamil Nadu Agricultural University, Tamil Nadu, India

[2]Assistant Professor (Plant Pathology), Regional Research Station, Paiyur, Krishnagiri, Tamil Nadu Agricultural University, Tamil Nadu, India

[3]Associate Professor (Plant Nematology), Regional Research Station, Paiyur, Krishnagiri, Tamil Nadu Agricultural University, Tamil Nadu, India

[4]Assistant Professor (Entomology), Regional Research Station, Paiyur, Krishnagiri, Tamil Nadu Agricultural University, Tamil Nadu, India

[5]Assistant Professor (Entomology), Regional Research Station, Paiyur, Krishnagiri, Tamil Nadu Agricultural University, Tamil Nadu, India

[6]Assistant Professor (Plant Pathology), TNAU Information and Training Centre, Chennai, Tamil Nadu Agricultural University, Tamil Nadu, India

*Corresponding Author: M. Deivamani

Introduction

An unfamiliar insect on a crop plant may look like a small, local problem. But if it is a newly introduced invasive species, that first unnoticed colony can become the starting point of a major agricultural emergency. Early detection, correct identification, quarantine, farmer vigilance, biological control, and rapid response are the strongest safeguards against this growing threat.

A WARNING HIDDEN IN PLAIN SIGHT

A coconut farmer may first notice a few unusual white insects beneath a leaflet. A maize farmer may find a caterpillar in the whorl that does not resemble the familiar stem borer. A

vegetable grower may observe tiny punctures on fruits, while a nursery owner may see a strange mealybug-like colony on newly arrived ornamental plants. Initially, these signs may appear too small to worry about. The affected plants may still look healthy, and the pest may be confined to a few leaves or a single field corner. Yet this is exactly how an invasive-pest problem can begin. An insect that enters a new region, survives local weather, finds an abundant crop host, and reproduces without strong natural regulation may spread very rapidly. By the time visible symptoms become widespread, the pest may already have moved through farms, nurseries, markets, roadsides, and neighbouring districts.



Figure 1. Plantation crops and mixed agricultural landscapes can be vulnerable to invasive pests when new insects find suitable host plants and favourable conditions for establishment

An invasive alien insect pest is an insect that has moved beyond its natural geographical range, established a breeding population, spread, and caused economic or ecological harm. Such insects may attack crops, plantation trees, forest plants, ornamentals, stored products, or native flora. Their arrival is closely associated with the movement of agricultural commodities, planting materials, nursery stock, timber, fruit consignments, cargo, and soil. Some insects travel as eggs hidden beneath leaves. Others survive as larvae inside fruits, stems, roots, trunks, or wooden packaging. Still others travel as pupae in soil or as adults in cargo and vehicles. Climate change, global trade, increased movement of people and materials, continuous cultivation, and expansion of high-value horticulture have all created more opportunities for invasive insects to enter, survive, and spread.



Figure 2. Rugose spiralling whitefly, Aleurodicus rugioperculatus, produces characteristic waxy spiral egg deposits and colonies on the underside of coconut leaves.

The importance of early detection lies in a simple fact: an insect is easiest to stop when it is found early, localized, and present in low numbers. Once it becomes established over a large area, eradication is often unrealistic. The objective then changes from eradication to long-term suppression, which may require regular monitoring, repeated pest-management interventions, increased production costs, and continuing risk to farmers. FAO identifies early warning, prevention, and rapid coordinated response as central elements of plant-pest management because transboundary pests can move across borders and threaten food systems, trade, and livelihoods.

WHY INVASIVE INSECTS SPREAD SO QUICKLY

The success of an invasive insect depends on several ecological advantages. First, the pest may enter a region where crops or host plants are abundant. A polyphagous pest such as fall armyworm can feed on several crop and weed hosts, allowing it to survive across seasons. A pest attacking plantation crops may find large, continuous areas of coconut, arecanut, banana, coffee, or ornamental palms. Second, the pest may arrive without the predators, parasitoids, pathogens, and competitors that kept it under partial control in its native region. This ecological release can allow the pest population to grow quickly.



Figure 3. Fall armyworm feeding causes ragged holes, window-like feeding injury, and damage to maize leaves.

Third, farmers and local extension systems may not recognize the insect immediately. A new whitefly can be mistaken for a familiar whitefly. A new caterpillar can be confused with an ordinary leaf feeder. A new borer may be noticed only after serious internal plant damage. The absence of local knowledge makes management difficult during the crucial initial period. There may be no approved lure, no locally validated economic threshold, no known biological-control agent, and no tested advisory for the local crop-production environment.

Fourth, invasive insects often take advantage of agricultural landscapes that provide abundant food throughout the year. Continuous cultivation, overlapping crop seasons, irrigated production, backyard host plants, weeds, abandoned fields, and poorly managed crop residues can all help a pest bridge the period between one crop and the next. Climate change can further strengthen this process. Warmer temperatures can shorten insect development time, increase the number of generations, and allow pests to survive in areas that were earlier too cool. Increased trade and climate suitability together create a powerful pathway for pest invasions.

INDIA'S RECENT LESSONS FROM INVASIVE PESTS

India has witnessed several examples that show why invasive-pest preparedness is urgently needed. Fall armyworm, *Spodoptera frugiperda*, is one of the clearest cases. Native to the Americas, it spread across Africa and was first reported in India in 2018. The pest became a major concern in maize because larvae feed on leaves, whorls, tassels, and cobs. Early larval feeding may produce window-like patches on leaves, whereas later instars cause large irregular holes, heavy frass accumulation, and damage deep inside the maize whorl. Since the insect feeds on numerous host plants, including maize, sorghum, millets, rice, sugarcane, and grasses, it can

persist in the agricultural landscape for extended periods. Its rapid invasion illustrated how an insect can move from a new detection to widespread concern when it has high mobility, multiple hosts, and favourable conditions.

Coconut-growing regions have also experienced the consequences of invasive whiteflies. Rugose spiralling whitefly, *Aleurodicus rugioperculatus*, was reported in India on coconut in 2016 and later spread to many coconut-growing landscapes. It colonizes the underside of leaves and produces conspicuous waxy spirals and filamentous deposits. The nymphs and adults suck plant sap and excrete honeydew. Black sooty mould grows on this honeydew, covering leaf surfaces and reducing photosynthesis. Coconut farmers often become alarmed when they see palms covered in white wax, sticky deposits, and blackened leaves. Such symptoms can create pressure for immediate insecticide spraying.

However, the rugose spiralling whitefly experience also demonstrated the importance of biological control. Research and extension efforts identified useful natural enemies, including the parasitoid *Encarsia guadeloupae*, predatory insects such as *Apertochrysa astur*, and entomopathogenic fungi such as Isaria fumosorosea. ICAR - NBAIR has trained stakeholders in the identification, mass production, release, and conservation of these biocontrol agents for suppression of invasive whiteflies. More recently, ICARâ€“IIOPR reported promising field performance of an entomopathogenic fungal isolate, *Aspergillus sp*. R55, against rugose spiralling whitefly, although farmers should use only authorized, locally recommended formulations and extension advice.

The major lesson is that indiscriminate pesticide use is not always the correct answer to an invasive pest. Broad-spectrum chemical sprays can kill parasitoids, predators, pollinators, and other beneficial organisms. When natural enemies are removed, whiteflies and other sap-feeding insects may recover rapidly. Sustainable management depends on accurate diagnosis, regular monitoring, conservation of natural enemies, field sanitation, and use of validated IPM practices.

QUARANTINE: STOPPING THE PEST BEFORE ENTRY

Plant quarantine is the first and most important barrier against invasive pests. It is a system of legal, scientific, technical, and inspection-based measures designed to prevent pests from entering a country, establishing in a new area, or spreading from one region to another. Quarantine is implemented at airports, seaports, land borders, plant-import stations, nurseries, seed-production areas, markets, and domestic movement routes. It involves inspection of

imported plants, seeds, fruits, cuttings, timber, soil, growing media, agricultural machinery, wooden packaging, and other materials that may carry harmful pests.



Figure 4. Plant-quarantine inspection of cargo and wooden packaging is a critical first barrier against accidental entry of invasive insect pests, pathogens, and other harmful organisms.

Phytosanitary certificates are important documents in this process. They indicate that a consignment has been inspected and meets the importing country's plant-health requirements. Depending on the risk, imported material may undergo treatment, laboratory testing, restricted entry, post-entry quarantine, or destruction if it is found to carry a harmful pest. Quarantine officers and diagnostic laboratories play a crucial role because many pests cannot be identified accurately by superficial examination alone. Eggs, larvae, pupae, mites, nematodes, fungal spores, bacterial pathogens, and viruses may remain hidden in plant materials.

For farmers, nursery owners, and agricultural entrepreneurs, quarantine begins with responsible sourcing. Planting material should be obtained from registered, traceable, and reliable sources. Informal exchange of nursery plants, ornamental palms, cuttings, suckers, seedlings, fruits, soil, or planting materials from unknown locations can introduce a pest into a new village or district. Farmers should avoid moving suspicious or infested plant material. A single infested palm sucker, nursery seedling, fruit consignment, or cutting can carry an insect to an unaffected region. Preventing this movement is far less costly than trying to manage an invasion after establishment.

INSPECTION: THE FARMER AS FIRST DETECTOR

No inspection agency can visit every field every day. Farmers, farm workers, nursery operators, local input dealers, students, extension staff, and community members are therefore

essential partners in early detection. Farmers understand what is normal in their fields. They know the usual pests of their crops, the expected pattern of damage, and the season when an insect normally appears. This local knowledge makes them the first line of surveillance.



Figure 5. Inspection of imported consignments at ports and entry points helps identify risky planting material, cargo, packaging, and produce before pests can enter agricultural landscapes

Regular inspection should be systematic rather than casual. Insects and their symptoms can be concealed in many locations. Whiteflies, scales, mealybugs, aphids, mites, and eggs are often found on the underside of leaves. Borers may remain inside stems, shoots, fruits, trunks, crowns, or leaf axils. Caterpillars can hide within maize whorls, rolled leaves, silk-webbed foliage, or soil. Fruit flies may be recognized through fruit punctures, premature fruit drop, maggots, or trap catches. Therefore, farmers should inspect leaf surfaces and undersides, tender new growth, shoots, flower clusters, fruits, crop whorls, bark, trunks, crowns, leaf axils, field borders, weeds, crop residues, and nearby host plants.

Farmers should pay special attention to unfamiliar insects, new waxy or cottony deposits, spiralling egg patterns, excessive honeydew, black sooty mould, unusual bore holes, frass, wilting shoots, unexplained fruit drop, dead central leaves, sudden defoliation, and pest damage outside the normal season. A pest found at an unusual elevation, in a new crop, or in a previously unaffected village should be treated as an important observation. Proper reporting begins with

clear photographs. The farmer should take close-up images of the insect or symptom and wider photographs showing the entire plant and field situation. The location, crop, date, crop stage, and approximate level of spread should be recorded. The observation should be reported without delay to agricultural extension officers, horticulture officers, Krishi Vigyan Kendras, agricultural universities, research stations, plant-protection officers, or diagnostic laboratories.

BIOLOGICAL CONTROL: NATURE'S LONG-TERM DEFENCE

Biological control is the use of living organisms to reduce pest populations. It can involve predators, parasitoids, entomopathogenic fungi, bacteria, viruses, nematodes, or other naturally occurring enemies of pests. Biological control is particularly valuable in invasive-pest management because many invasive insects become severe after escaping their natural enemies in their original region.

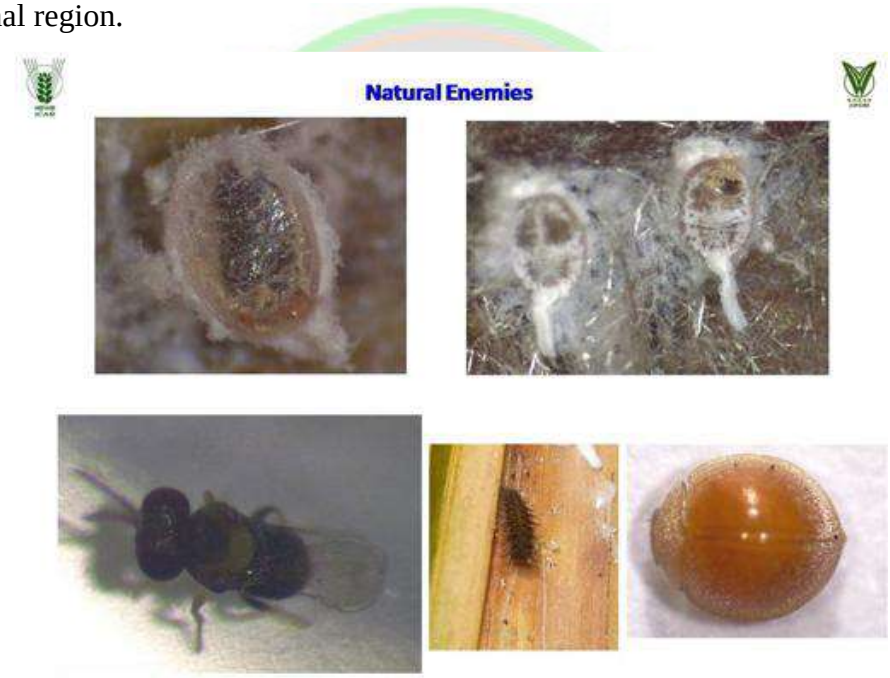


Figure 6. Natural enemies, including parasitoid wasps, ladybird beetles, and predatory larvae, can contribute substantially to suppression of invasive whitefly populations.

There are three major forms of biological control. Conservation biological control focuses on protecting the beneficial organisms already present in the crop ecosystem. This includes reducing unnecessary pesticide use, selecting safer and more selective products when treatment is needed, preserving flowering resources where suitable, and maintaining habitat diversity. Augmentative biological control involves mass multiplication and release of beneficial organisms, such as parasitoid wasps, ladybird beetles, lacewings, predators, or microbial

biopesticides. Classical biological control involves introducing a specialized natural enemy from the pests native range after thorough scientific assessment, quarantine testing, and regulatory approval.



Figure7. The parasitoid wasp Encarsia guadeloupae is an important natural enemy associated with suppression of rugose spiralling whitefly in coconut ecosystems.

India has a notable record in the use of classical biological control against invasive pests. A 2026 review documented the importation of 174 natural enemies into India, with 77 becoming established. The review identified 48 successful biological-control cases against 15 invasive weeds and 13 invasive arthropod pests. Such achievements show the potential of biological control, but they also underline the need for caution. Introducing a natural enemy requires expert assessment of host specificity, effectiveness, adaptation to local climate, safety to native organisms, and compatibility with local farming systems. Individual farmers should never release unverified biological organisms. They should follow the advice of authorized research institutions and plant-protection agencies.

FARMER VIGILANCE AND DIGITAL SURVEILLANCE

Farmer vigilance is not about creating fear. It is about observing carefully, documenting correctly, reporting early, and acting responsibly. A vigilant farmer recognizes that a strange insect may have implications beyond one field. By sharing a clear report quickly, the farmer can help technical agencies conduct surveys, identify the insect, and alert neighbouring growers. Invasive-pest surveillance works best when individual observations are linked to community action.

Farmer groups, producer organizations, coconut-grower associations, coffee-grower groups, self-help groups, and village-level communication networks can help share verified pest alerts. However, pest information should be confirmed by technical experts before it is circulated widely. Incorrect identification can lead to unnecessary fear and misuse of pesticides. Extension agencies should provide simple guides containing photographs of major invasive pests, their symptoms, key natural enemies, reporting contacts, and recommended immediate actions.



Figure 8. Smartphone-based reporting enables farmers to photograph unusual insects or symptoms, record location details, and seek rapid expert confirmation.

Digital tools can strengthen the surveillance network. Smartphones allow field photographs to be captured and shared rapidly. GPS-enabled reporting can map suspected occurrences. Mobile applications can record pest observations and send them to experts. Smart pheromone, light, sticky, and food-bait traps can transmit pest-catch data from the field. GIS platforms can display pest distribution and highlight emerging hotspots. Artificial intelligence can help sort images, trap records, weather data, and crop-stage information to identify locations requiring inspection. Early-warning systems for invasive alien species increasingly emphasize targeted inspection, trapping at points of entry, and use of molecular diagnostic tools to support timely action.

RAPID RESPONSE: ACTING IN THE FIRST DAYS

When an invasive pest is confirmed, rapid response is essential. The first objective is accurate identification. Scientists and diagnostic laboratories must determine exactly what the insect is. The second objective is delimiting the infestations finding out how far the pest has

spread. This requires systematic surveys in the original field, nearby farms, nurseries, markets, transport routes, host-plant areas, and potentially affected villages. The third objective is containment. Movement of infested plant material, fruits, seedlings, cuttings, soil, crop residues, or nursery plants may need to be restricted until the risk is understood.

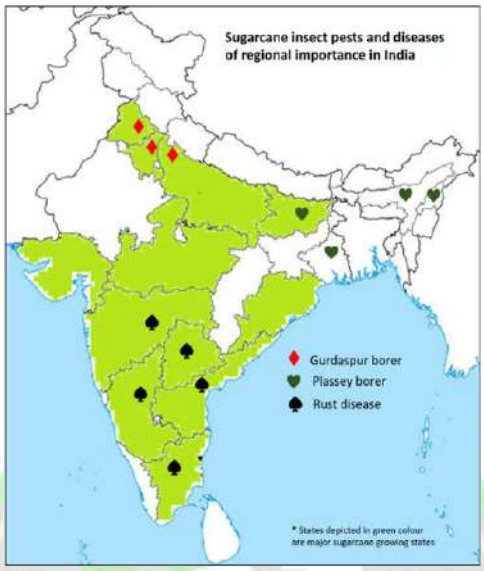


Figure 9. Pest-distribution mapping supports quarantine, surveillance, and rapid-response decisions by showing where invasive or emerging pests occur and where further inspection is required.

The fourth objective is management. Depending on the pest, this may involve destruction or safe treatment of infested materials, field sanitation, trapping, deployment of biocontrol agents, targeted crop-protection measures, and continued surveillance. The response should be based on the biology of the pest, the extent of spread, the crop affected, local climatic conditions, and potential risks to non-target organisms. A rapid-response team may include farmers, extension officers, plant-quarantine authorities, entomologists, diagnosticians, agricultural universities, research institutions, and local government bodies.

Clear communication is essential throughout this process. Farmers need to know what the pest looks like, what plant materials should not be moved, how to report new findings, which beneficial insects should be protected, and what immediate actions they can take. Rumours and unverified pesticide recommendations can cause more harm than good. A well-coordinated response replaces panic with practical action.

WHAT FARMERS CAN DO NOW

1. Inspect crops and nursery plants regularly. Examine the underside of leaves, young shoots, crop whorls, fruits, crowns, trunks, plant residues, weeds, and nearby host plants. Look for unfamiliar insects, unusual wax deposits, honeydew, sooty mould, bore holes, frass, sudden wilting, or damage outside the normal season.
2. Document and report suspicious pests promptly. Take clear photographs of the insect and the symptoms, record the crop, village, date, and extent of infestation, and report the case to nearby agricultural or horticultural officers, KVK scientists, agricultural universities, or plant-protection personnel.
3. Do not move suspicious plant materials. Avoid transporting seedlings, suckers, cuttings, fruits, palms, nursery plants, soil, crop residues, or packing materials from a suspected field to unaffected areas until expert advice is received.
4. Avoid indiscriminate pesticide use. Do not spray broad-spectrum insecticides before the pest is correctly identified. Such sprays may kill beneficial parasitoids, predators, pollinators, and other organisms that help suppress invasive pests.
5. Support community surveillance and IPM. Share verified pest information with neighbouring farmers, cooperate with field surveys, maintain sanitation, conserve natural enemies, and adopt only authorized biological-control and IPM recommendations.

A FUTURE BUILT ON EARLY WARNING

The next invasive pest may not arrive with a dramatic announcement. It may begin with a few unusual insects on a nursery plant, a strange caterpillar in a maize whorl, a waxy colony on a coconut leaflet, a suspicious fruit puncture, or an unfamiliar beetle caught in a trap. The difference between a small warning and a widespread agricultural crisis depends on how quickly and intelligently the agricultural community responds.

Quarantine reduces the chance that harmful insects will enter. Inspection identifies early signs in fields and nurseries. Farmer vigilance provides the first alert. Diagnostic laboratories confirm the identity of the pest. Biological control helps restore ecological balance. Rapid-response systems contain outbreaks. Digital surveillance strengthens communication and decision-making. Integrated pest management provides the long-term, sustainable strategy after a pest has established.

The next invasive pest could indeed be at our doorstep. But a well-informed farmer, a vigilant community, strong quarantine, accurate diagnosis, conservation of natural enemies, and a coordinated rapid-response system can stop a small warning sign from becoming the next major agricultural emergency in India.

References

Food and Agriculture Organization of the United Nations. (2026, February 13). Getting ahead of emerging plant pests of global concern. FAO.

Jethva, D. M., Wadaskar, P. S., & Kachot, A. V. (2020). First report of rugose spiraling whitefly, Aleurodicus rugioperculatus Martin (Hemiptera: Aleyrodidae) on coconut in Gujarat, India. Journal of Entomology and Zoology Studies, 8(2), 722 - 725.

Muniappan, R., Subaharan, K., Selvaraj, K., Sampathkumar, M., & Sushil, S. N. (2026). Role of biological control in management of invasive exotic arthropod pests and weeds in India. Insects, 17(1), 61. https://doi.org/10.3390/insects17010061

Palanivelu, K., Saminathan, N., Muthusamy, D. D., Arunachalam, A., & Kolanchi, P. (2026). Silent invaders crossing borders: Unfolding the biosecurity, ecological, and management frontiers of emerging insect pests in India. Proceedings of the Indian National Science Academy. https://doi.org/10.1007/s43538-026-00783-1

Sharanabasappa, K., Kalleshwaraswamy, C. M., Asokan, R., Mahadeva Swamy, H. M., Maruthi, M. S., Pavithra, H. B., Hegde, K., Navi, S., Prabhu, S. T., & Goergen, G. (2018). First report of fall armyworm, Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae), an alien invasive pest on maize in India. Pest Management in Horticultural Ecosystems, 24(1), 23 - 29.

Volume: 06 Issue No: 09

SOIL CARBON SEQUESTRATION: TURNING INDIAN SOILS INTO CLIMATE SOLUTIONS

Article ID: AG-V06-I09-08

Prabakaran. S

Assistant Professor, VIA, Pollachi, Tamil Nadu, India

Introduction

Apart from serving as a medium for crop growth, soil is one of the largest reservoirs of carbon on Earth and plays a critical role in regulating climate, water and nutrient cycles. In Indian agriculture, intensive cultivation, residue removal, soil disturbance and declining organic matter have affected soil health in many regions. Soil carbon sequestration offers an opportunity to address climate change while simultaneously improving agricultural productivity and resilience.

Carbon sequestration refers to the process of capturing atmospheric CO_2 through photosynthesis and transferring carbon into soil, where it is stored as soil organic carbon for varying periods.

Potential of Indian soils

India has an enormous opportunity for soil carbon management due to its diverse soils, cropping systems and agro-climatic conditions. Practices that increase carbon inputs and reduce carbon losses can improve SOC while providing co-benefits such as better soil structure, water-holding capacity, nutrient cycling and drought resilience.

It has been found that regenerative agricultural practices such as application of biochar, farmyard manure, green manure, compost and appropriate fertilizer management showed substantial benefits, while conservation tillage and residue retention produced moderate but consistent improvements. Importantly, SOC gains were generally greater when practices were maintained for longer periods, particularly beyond five years.

Indian croplands could potentially increase soil carbon stocks by approximately 0.3–0.6 t C/ha/year, offering significant climate-mitigation potential.

Methods of improving sequestration

a. Conservation agriculture

- Reduced tillage, minimum tillage and zero tillage reduce soil disturbance and can decrease oxidation of soil organic matter.
- Retaining crop residues on the soil surface also returns carbon to the soil.

b. Crop-residue management

- Instead of burning or removing residues, farmers can retain residues on soil surface, incorporate suitable residues, use residues as mulch, compost residues, convert suitable biomass into biochar.

c. Organic manures and compost

- FYM, compost, vermicompost and other stabilized organic amendments add carbon to soil while supplying nutrients.

d. Green manuring and cover crops

- Green manure and cover crops capture atmospheric CO_2 during their growth and transfer carbon below ground through roots and residues.
- Leguminous cover crops additionally contribute through biological nitrogen fixation.

e. Biochar

- Biochar is carbon-rich material produced by heating biomass under limited oxygen.
- Application of biochar has the capability improving carbon sequestration.

f. Agroforestry

- Integrating trees with crops or livestock can increase carbon storage in tree biomass, roots, litter and soil organic matter.

g. Improved nutrient management

- Balanced fertilization and integrated nutrient management can increase crop biomass and root production, thereby increasing carbon inputs into soil.

h. Better water management

- Efficient irrigation, alternate wetting and drying (for rice), drainage management and precision water application can influence both carbon sequestration and greenhouse-gas emissions.

Emerging soil-carbon projects in India

India is moving from academic discussions towards field demonstrations on carbon sequestration through carbon farming programmes and agricultural carbon-market projects. In recent years, ICAR institutes have shifted their focus towards carbon farming and carbon-market frameworks. IARI is disseminating knowledge to farmers on carbon credits, soil, crop and water management, biochar, horticulture and agroforestry as components of carbon projects.

In 2025, ICAR-ATARI Ludhiana collaborated with Grow Indigo to promote regenerative and climate-smart agriculture, capacity building and carbon-credit generation.

KVK, Nadia, West Bengal, became India's first net-zero certified KVK in 2025. An indigenous Agriculture Carbon Footprint Assessor was developed to support farm-level carbon accounting. Carbon Pathshala programme in Madhya Pradesh, organized by ICAR-IISS, introduced farmers to carbon markets, regenerative agriculture and soil-carbon opportunities.

Green Credit Programme (GCP), launched by the Ministry of Environment, Forest and Climate Change, encourages water conservation and tree plantation through tradable green credits.

Conclusion

Soil carbon sequestration offers a promising pathway to combat climate change, restore soil health and strengthen agricultural resilience. Integrating conservation agriculture, organic amendments, biochar, agroforestry, nutrient management supported by robust monitoring and equitable carbon markets, can enhance long-term carbon storage while improving farmer livelihoods and sustaining food security.

References

Patil, M., Perumal, C., Choudhari, P. L., Pasumarthi, R., Sawargaonkar, G. L., & Singh, R. (2025). Differential impacts of regenerative agriculture practices on soil organic carbon: A meta-analysis of studies from India. Scientific Reports, 15, 33470.

Yadav, D., Singh, D. V., Babu, S., Madhu, M., & Kumawat, A. (2025). Carbon farming: Innovations, potential, and challenges for sustainable future. Indian Journal of Agronomy, 70.

Babu, S., Raj, R., Pandey, A., Rathore, S. S., & Srinivas Rao, C. (2025). Carbon farming: Practices and challenges. Indian Farming, 75(12), 49–52.

Kundu, S., Srinivasarao, C., Reddy, K. S., Prasad, J. V. N. S., Indoria, A. K., Veni, V. G., & Singh, V. K. (2022). Soil carbon management in rainfed production systems. Indian Farming, 72(11), 54–57.

Rao, A. S., Jha, P., & Biswas, A. K. (2020). Carbon sequestration in agricultural soils: Issues and strategies. Indian Journal of Agroforestry, 13(2)

Volume: 06 Issue No: 09

BALANCED USE OF FERTILIZERS IN AGRICULTURE

Article ID: AG-VO6-I09-09

S. Rathika*, N.Punithavathi and M.Sakila

ICAR - Krishi Vigyan Kendra, Tamil Nadu Agricultural University, Sirugamani, Tiruchirappalli Tamil Nadu, India

*Corresponding Author: S. Rathika

Introduction

Agriculture is the backbone of human survival, providing food, raw materials, and employment to a significant portion of the global population. In developing countries like India, agriculture not only ensures food security but also supports rural livelihoods and contributes to the national economy. With the global population expected to rise steadily, the pressure on agriculture to produce more food from limited land resources is increasing. To meet this demand, modern agriculture has become highly dependent on external inputs, particularly fertilizers. Fertilizers are substances that supply essential nutrients to plants, helping them grow faster and produce higher yields. During the Green Revolution, the introduction of high-yielding varieties along with the increased use of fertilizers led to a remarkable rise in food production. However, this success came with unintended consequences. Over time, farmers began applying fertilizers indiscriminately, often focusing on nitrogen-based fertilizers such as urea due to their quick and visible effects on crop growth. In Tamil Nadu, consumption of fertilizers increased from 9.65 lakh metric tonnes in 2019-20 to 10.68 lakh metric tonnes in 2023-24. In India, total fertilizer ($N+P_2O_5+K_2O$) consumption reached 32.93 million tonnes in 2024-25, with a fertilizer use intensity of 151 kg/ha. The average fertilizer consumption ratio (9.3:3.5:1) is highly skewed towards N. This led to an imbalance in nutrient application, where some nutrients were applied excessively while others were neglected. As a result, soils became deficient in several essential nutrients, leading to declining productivity and soil health.

Moreover, excessive fertilizer use has contributed to environmental problems such as water pollution, soil degradation, and greenhouse gas emissions. These issues highlight the need for a more scientific and sustainable approach to nutrient management. Balanced fertilization is one such approach that aims to optimize fertilizer use by ensuring that all essential nutrients are supplied in the right proportion. It is not just about increasing crop yield but also about maintaining soil fertility, improving nutrient efficiency, and protecting the environment. Thus, balanced fertilization forms a critical component of sustainable agriculture.

Concept of Balanced Fertilization

Balanced fertilization is a comprehensive nutrient management strategy that ensures the supply of all essential nutrients to crops in adequate and appropriate proportions. Plants require a combination of macro, secondary, and micronutrients to complete their life cycle.

Macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) are required in large quantities. Nitrogen is a key component of amino acids, proteins, and chlorophyll, making it essential for vegetative growth. Phosphorus is involved in energy transfer, root development, and flowering, while potassium regulates water balance, enzyme activation, and disease resistance. Secondary nutrients like calcium, magnesium, and sulfur also play important roles. Calcium strengthens cell walls, magnesium is a central component of chlorophyll, and sulfur is essential for protein synthesis. Micronutrients, though required in trace amounts, are critical for various biochemical and physiological processes. For example, zinc is involved in enzyme activation and growth regulation, iron is necessary for chlorophyll formation, and boron is important for reproductive development. Deficiencies of micronutrients can significantly affect crop productivity.

Balanced fertilization ensures that these nutrients are supplied in the correct ratio. According to Liebig's Law of the Minimum, if one nutrient is deficient, it can limit plant growth even if other nutrients are abundant. In addition, balanced fertilization considers factors such as soil type, cropping system, climate, and crop variety. It is not a one-size-fits-all approach but a location-specific and crop-specific strategy.

Importance of Balanced Fertilizer Use

Balanced fertilization is crucial for improving agricultural productivity and sustainability. Its importance extends beyond crop yield to include soil health, economic benefits, and environmental protection.

- One of the primary benefits is enhanced crop productivity. When plants receive all essential nutrients in the right proportion, they grow more efficiently, resulting in higher yields. Balanced fertilization ensures that no nutrient becomes a limiting factor.
- It also improves crop quality. For example, potassium improves grain filling and increases resistance to diseases, while sulfur enhances oil content in oilseed crops. Balanced nutrition leads to better taste, appearance, and nutritional value of produce.
- Another important aspect is soil fertility maintenance. Continuous cropping removes nutrients from the soil, and if these nutrients are not replenished, soil fertility declines. Balanced fertilization restores nutrient levels and maintains soil productivity.
- From an economic perspective, balanced fertilization increases nutrient use efficiency, reducing wastage and lowering input costs. Farmers can achieve higher returns with optimal fertilizer use.
- Environmentally, balanced fertilization minimizes nutrient losses through leaching and runoff, reducing pollution of water bodies and greenhouse gas emissions.

Problems Associated with Imbalanced Fertilizer Use

Imbalanced fertilizer use has several negative consequences on soil, crops, and the environment.

- One major issue is soil degradation. Excessive use of nitrogen fertilizers leads to soil acidification, which reduces nutrient availability and microbial activity. It also affects soil structure and water-holding capacity.
- Nutrient imbalance is another problem. Overuse of one nutrient can suppress the uptake of others. For example, excessive nitrogen can reduce potassium uptake, leading to poor plant health.
- Environmental pollution is a serious concern. Nitrogen fertilizers can leach into groundwater as nitrates, posing health risks such as methemoglobinemia. Phosphorus runoff can cause eutrophication of water bodies, leading to algal blooms and oxygen depletion.
- Imbalanced fertilization also increases susceptibility to pests and diseases. Excess nitrogen promotes lush vegetative growth, which attracts pests and weakens plant resistance.
- Additionally, excessive nitrogen can cause lodging in crops like rice and wheat, reducing yield and complicating harvesting.

- Economically, farmers incur losses due to inefficient fertilizer use and reduced crop productivity.

Status of Fertilizer Use in India

India's fertilizer consumption pattern reflects a significant imbalance, with a heavy emphasis on nitrogenous fertilizers. This is largely due to government subsidies on urea, making it more affordable compared to other fertilizers. The recommended N:P:K ratio is approximately 4:2:1, but actual usage often exceeds this ratio in favor of nitrogen. This imbalance has led to widespread nutrient deficiencies, particularly of phosphorus, potassium, and micronutrients.

Different regions exhibit varying patterns of fertilizer use. In intensive farming areas, continuous cropping has led to nutrient depletion and soil fatigue. Micronutrient deficiencies, especially zinc, iron, and sulfur, are increasingly reported across Indian soils. These deficiencies affect crop yield and quality. Efforts are being made to promote balanced fertilization through policy interventions and farmer awareness programs.

Principles of Balanced Fertilization

The concept of balanced fertilization is guided by the 4R Nutrient Stewardship framework.

- The right source involves selecting fertilizers that match crop needs and soil conditions. For example, using slow-release fertilizers can improve nutrient efficiency.
- The right rate ensures that nutrients are applied in appropriate amounts based on soil testing and crop requirements. Over-application leads to wastage and environmental damage.
- The right time ensures that nutrients are available when crops need them most. Split application of nitrogen is a common practice to improve efficiency.
- The right method involves proper placement and application techniques. Methods like band placement and fertigation reduce nutrient losses and enhance uptake.

Modern approaches of balanced fertilization

1) **Soil Test-Based Fertilizer Recommendations:** Soil testing is a fundamental and essential step in balanced fertilization. Based on test results, soils are classified as low, medium, or high in nutrient content. Fertilizer doses are increased for nutrient-deficient soils and reduced where nutrient levels are already sufficient. The Soil Health Card Scheme supports this approach by providing farmers with field-specific soil data, enabling them to apply fertilizers more accurately and avoid excessive use.

2) **Soil Test Crop Response (STCR) Approach:** The STCR approach links fertilizer application directly with crop yield targets. It takes into account soil nutrient status, crop type, and local climatic conditions to calculate the exact nutrient requirements to achieve a desired yield. This method prevents over- and under-application of fertilizers, improves nutrient-use efficiency, and supports sustainable crop production.
3) **Integrated Nutrient Management (INM):** Integrated Nutrient Management combines chemical fertilizers with organic and biological sources to maintain soil fertility. Organic manures improve soil structure, increase microbial activity, and enhance nutrient availability. Green manuring add organic matter and improves soil health. Bio fertilizers fix atmospheric nitrogen and solubilise phosphorus, reducing dependency on chemical fertilizers. The integration of these sources ensures a balanced supply of nutrients and reduces dependence on chemical fertilizers. INM ensures sustainable agriculture by maintaining soil health and reducing environmental impact.
4) **Customised Fertilizers through Technology:** Customised fertilizers are formulated to meet the nutrient needs of a specific crop and soil. These fertilizers contain both macro and micronutrients in scientifically determined proportions.

   For example, micronutrients like zinc, boron, and sulphur can be blended with urea or DAP based on local soil deficiencies. This targeted application helps reduce nutrient losses, improve fertilizer efficiency, and lead to better crop response.
5) **Diagnosis and Recommendation Integrated System (DRIS):** This approach analyses plant tissue to evaluate nutrient ratios such as nitrogen to phosphorus (N/P) or nitrogen to potassium (N/K), rather than focusing solely on absolute nutrient values When imbalances are detected, corrective measures-usually through top dressing-are recommended. This approach is beneficial for long-duration crops and has also shown positive results in wheat and soybeans.
6) **Site-Specific Nutrient Management (SSNM):** It focuses on applying fertilizers according to a crop's actual needs and soil variability within a field. Instead of using a uniform fertilizer dose, it ensures nutrients are applied only where and when they are required.
7) **Fertigation** allows efficient nutrient application through irrigation.

Benefits of balanced fertilization

- Higher crop productivity and optimal performance of High Yielding Varieties.

- Better crop quality and Stress resistance.
- Balanced fertilization reduces environmental pollution by minimizing nutrient losses.
- It helps in reducing greenhouse gas emissions and improving soil carbon sequestration.
- Improved nutrient management protects water quality and supports sustainable agriculture.
- Cost-Effective input use.

Government Initiatives

1) Soil Health Card (SHC) Launched in 2015, Scheme provides farmers with a scientifically generated, plot-wise diagnostic report for each landholding, based on scientific soil testing. The card assesses soil health across twelve key parameters. Issued every two years, the soil health card provides farmers with a comprehensive understanding of the nutrient status and physicochemical conditions of their soils. It also offers crop-specific recommendations on the appropriate use of chemical fertilizers, bio-fertilizers, organic inputs, and soil treatments to support informed decision-making and long-term soil health management. By July 2025, the scheme had provided more than 93,000 farmer training programmes, approximately 6.8 lakh field demonstrations, and thousands of awareness campaigns. As of mid-November 2025, over 25.55 crore soil health cards have been distributed across the country, reflecting the scale and outreach of the scheme in promoting balanced nutrient management.

2) The **Nutrient-Based Subsidy (NBS)** Scheme promotes balanced use of essential nutrients such as nitrogen, phosphorus, potassium, and sulphur, helping farmers avoid over-reliance on a single fertilizer and maintain soil health while improving crop productivity. Under the scheme, the Government provides a fixed subsidy on phosphatic and potassic (P&K) fertilizers, including DAP, with subsidy rates linked to each fertilizer's nutrient content and revised periodically. The approved NBS rates for Rabi 2025-26 are effective from October 1, 2025, to March 31, 2026. Between 2022–23 and 2024-25, more than 2.04 lakh crore in subsidies were allocated for both indigenous and imported phosphatic and potassic (P&K) fertilizers.

3) Neem-coated urea: The Government mandated a 100 percent neem coating on all domestically produced urea, permitting fertilizer manufacturers to levy a maximum retail price (MRP) up to 5 percent higher, to offset the associated costs. This requirement was implemented from September 2015 for indigenously manufactured urea and from December 2015 for

imported urea, resulting in the complete transition of the national urea supply to neem-coated formulations.

Neem-coated urea is conventional urea treated with neem oil, which acts as a nitrification inhibitor and slows the release of nitrogen in the soil, thereby synchronizing nutrient availability with crop demand. This improves nitrogen use efficiency, reduces nutrient losses, and reduces fertilizer overuse. It enables farmers to reduce urea consumption. Consequently, the adoption of neem-coated urea contributes to improved soil health and greater efficiency in agricultural production systems.

4) Paramparagat Krishi Vikas Yojana: Launched in 2015, the Paramparagat Krishi Vikas Yojana (PKVY) promotes organic farming by providing financial assistance of Rs. 31,500 per hectare over a three-year period. The scheme supports balanced nutrient management by integrating traditional agricultural practices with sustainable soil fertility approaches, including the use of compost, biofertilizers, and organic matter. As of 31st October 2025, a total area of 16.90 lakh ha has been covered under PKVY since its inception.

5) PM-PRANAM Scheme: The PM-PRANAM Scheme (Prime Minister Programme for Restoration, Awareness, Nourishment and Amelioration of Mother Earth) focuses on reducing the use of chemical fertilizers and promoting balanced nutrient application. The scheme encourages the adoption of eco-friendly alternatives such as organic manure, bio-fertilizers, and compost. The scheme includes a provision to incentivise States and UTs to reduce chemical fertilizer (urea, DAP, NPK, and MOP) consumption during a given financial year compared to the average consumption of the preceding three years, with incentives equivalent to 50 percent of the fertilizer subsidy savings achieved. During FY 2023–24, 14 States recorded a reduction of 15.14 lakh metric tonnes in chemical fertilizer consumption relative to the average of the previous 3 financial years.

6) Promotion on Nano Fertilizers: Nano Fertilizers are plant nutrients packaged in tiny particles called nanomaterials, allowing nutrients to be released slowly and absorbed by crops more efficiently, with minimal waste.

To promote their adoption, the Department of Fertilizers has undertaken key initiatives:

- Awareness campaigns through workshops, webinars, field demonstrations, street plays, and regional films.

- Availability of nano urea and nano Diammonium Phosphate (DAP) at Pradhan Mantri Kisan Samridhi Kendras (PMKSKs) nationwide.
- Integration of nano urea into monthly fertilizer supply planning to ensure availability.
- Nationwide promotion of balanced fertilizer use, including nano variants
- Organization of a "Maha Abhiyan" to promote the adoption of nano Diammonium Phosphate (DAP) across all 15 agro-climatic zones, supported by field demonstrations and structured farmer interactions
- Promotion of drone-based spraying and battery-operated sprayers to enable efficient and cost-effective application, supported by trained village-level entrepreneurs
- Encouragement to fertilizer companies to expand and scale up the production of nano-fertilizer

7) Development of customized and fortified fertilizers: The government has been promoting the adoption of fortified, soil, crop, and area-specific fertilizers tailored to nutrient needs. Under the Nutrient-Based Subsidy (NBS) policy, subsidised phosphatic and potassic (P&K) fertilizer variants fortified or coated with micronutrients such as boron and zinc are eligible for subsidy support. In addition, these fortified or coated fertilizers receive an additional subsidy per metric tonne (MT) to incentivise their use alongside primary nutrients and encourage balanced nutrient application.

Challenges in Adoption of balanced fertilization

- Lack of awareness, limited soil testing facilities, and high cost of inputs.
- Farmers often rely on traditional practices and prefer quick results.
- Extension services need to be strengthened to promote balanced fertilization.

Future Strategies

- Improving awareness, promoting soil testing, and adopting advanced technologies.
- Encouraging integrated nutrient management, organic farming and natural farming will enhance sustainability.
- Policy support and research innovations are essential.

Conclusion

Balanced use of fertilizers is a cornerstone of sustainable agriculture, as it ensures optimal crop productivity while maintaining soil health and minimizing environmental impact. The indiscriminate use of fertilizers in the past has led to several challenges, including soil

degradation, nutrient imbalance, and environmental pollution. Balanced fertilization addresses these issues by promoting the efficient and judicious use of nutrients based on scientific principles. It enhances nutrient use efficiency, improves crop yield and quality, and supports long-term soil fertility. The integration of organic, inorganic, and biological nutrient sources through integrated nutrient management further strengthens the sustainability of agricultural systems. Despite the challenges in adoption, advancements in technology, policy support, and increased awareness among farmers offer promising opportunities for promoting balanced fertilization. By adopting balanced nutrient management practices, farmers can achieve higher productivity, reduce input costs, and contribute to environmental conservation. Ultimately, balanced fertilization is not just a technical practice but a fundamental requirement for ensuring food security, economic stability, and ecological sustainability for future generations.

References

Arteaga, J and K Deininger. (2025). Yield Gains from Balancing Fertilizer Use: Evidence from Eastern India, World Bank Policy Research Working Paper, WPS 11134.

Bora, Kaushik. (2022). Spatial patterns of fertilizer use and imbalances: Evidence from rice cultivation in India, Environmental Challenges, 7: 100452.

Chand, Ramesh and Lal Mani Pandey. (2009). Fertiliser Use, Nutrient Imbalances and Subsidies: Trends and Implications, Margin: The Journal of Applied Economic Research, 3(4): 409-432.

Cissé, L. (2007). Balanced fertilization for sustainable use of plant nutrients. In: Part 1: General principles of FBMPs (p. 33). World Phosphate Institute (IMPHOS), Morocco.

Kushwah, M., Kumar, S., & Kumar, S. Balanced nutrient fertilisation: An approach for agricultural sustainability. Volume 3 (Issue 3), Article ID: AL2021150. ICAR–NDRI, Karnal, Haryana, India.

Mahajan, A., & Gupta, R. D. (2009). Balanced use of plant nutrients. In Integrated nutrient management (INM) in a sustainable rice-wheat cropping system. Springer. https://doi.org/10.1007/978-1-4020-9875-8_8.

Wanjari, R. H., Kumar, D., Singh, M., & Nagwanshi, A. (2022). Balanced use of fertilizers: A key for sustaining crop productivity and soil quality. Indian Farming, 34.

Volume: 06 Issue No: 09

CULTIVATION AND UTILITY OF FIG IN RAJASTHAN

Article ID: AG-VO6-I09-10

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture, Sri Karan Narendra Agriculture University (SKNAU), Jobner -303329, Rajasthan, India

Introduction

Fig (*Ficus carica L.*), commonly known as **Anjeer**, is an important subtropical fruit crop belonging to the family **Moraceae**. It is valued for its nutritious fruits, which are consumed fresh, dried, and processed. Rajasthan's arid and semi-arid climate is well suited for fig cultivation because the crop thrives under hot, dry conditions with moderate irrigation. ICAR has reported successful expansion of fig cultivation in western Rajasthan, especially in Barmer district, where the cultivated area has increased significantly in recent years

Climate

- Warm and dry climate is ideal.
- Optimum temperature: **15–35°C**.
- Mature plants can tolerate temperatures up to **45°C**.
- Low humidity during fruit ripening improves fruit quality.
- Excess rainfall during ripening may cause fruit cracking and rotting.

Suitable Areas in Rajasthan

Fig cultivation is suitable in: Barmer, Jalore, Jodhpur, Pali, Nagaur, Bikaner, Sikar, Alwar (with irrigation)

Soil

- Well-drained sandy loam to loamy soil.
- Soil pH: **6.0–7.5**.
- Avoid waterlogged soils.
- Good organic matter improves growth.

Recommended Varieties

- Dyna (widely grown in western Rajasthan), Poona Fig, Deanna, Conadria and Bellary

Planting Season

- **July–August** (monsoon) **February–March** (with irrigation)

Spacing

- Normal planting: **5 × 5 m**
- High-density planting: **4 × 4 m** (commonly adopted in Rajasthan)

Propagation

- Hardwood stem cuttings Air layering Tissue culture (commercial nurseries)

Irrigation

- Drip irrigation is recommended.
- Irrigate every **7–10 days** during summer.
- Reduce irrigation during fruit ripening for better sweetness and quality.

Manure and Fertilizer

Per plant per year:

- FYM: **20–25 kg** Nitrogen: **500 g**
- Phosphorus: **250 g** Potassium: **250 g**

Apply fertilizers in two equal splits:

- Before flowering
- After fruit set

Training and Pruning

- Train plants to an open-centre shape.
- Annual pruning after harvest encourages new shoots and better fruiting.

Flowering and Fruiting

- Plants begin bearing fruits in the **3rd year**.
- Peak production starts from the **5th year**.
- Fruits mature **60–80 days** after flowering.

Plant Protection

Common pests:

- Stem borer Fruit fly Mealy bugs

Common diseases:

- Leaf spot Rust Root rot

Integrated pest and disease management with orchard sanitation, monitoring, and recommended plant protection measures helps reduce losses.

Yield

- Average yield: **15–20 kg fruits per plant** under good management.
- Commercial orchards can produce **8–12 tonnes per hectare** depending on variety and management.

Harvesting

- Harvest when fruits become soft, fully colored, and slightly drooping.
- Fruits are harvested manually every **2–3 days** during the season.

Uses

- Fresh consumption Dry figs Jam and jelly
- Bakery products Health foods due to high fiber, calcium, iron, and antioxidants

Advantages of Fig Cultivation in Rajasthan

- Well suited to arid and semi-arid climate.
- Drought tolerant after establishment.
- High market value.
- Suitable for drip irrigation systems.
- Good export and processing potential.
- Can diversify farmers' income in dry regions.

Importance of Fig Farming

Fig farming (Anjeer cultivation) is rapidly emerging as a highly profitable and climate-resilient alternative for farmers across Rajasthan. Driven by institutional backing from bodies like the Indian Council of Agricultural Research (ICAR) and regional Krishi Vigyan Kendras (KVKs), it is turning the state's harsh climate into a distinct commercial advantage.

The government has also recognized this strategic potential by establishing a dedicated **Center of Excellence for Fig in Sirohi** to boost cultivation and processing.

1. Absolute Agro-Climatic Suitability: Rajasthan provides the precise environmental baseline required for commercial fig production:

High Temperature & Heat Tolerance: Fig trees thrive in dry, arid sub-tropical climates with summer temperatures fluctuating between 35°C to 45°C.

Abundant Sunlight: Clear desert skies ensure maximum sunshine hours, accelerating photosynthesis and leading to higher sugar accumulation in fruits.

Low Humidity Benefits: Excessive rain causes fruit cracking and fungal diseases. Rajasthan's low moisture profile keeps the fruit skins intact and healthy.

Salinity Tolerance: Figs are among the most **salt-tolerant fruit crops**. They grow exceptionally well in the calcareous and brackish water zones common to western Rajasthan.

2. High Financial Returns and Corporate Tie-ups

Compared to traditional pearl millet (Bajra) or cluster bean (Guar) farming, figs offer massive economic upgrades:

Per-Hectare Net Earnings: Commercial growers of varieties like "Dyna" are generating an annual net income of **₹5,00,000 to ₹6,00,000 per hectare**.

Per-Tree Revenue Yield: A single mature tree yields 15–20 kg of fresh raw material, earning the farmer approximately ₹1,500 to ₹2,000 per tree.

Contract Farming Options: Due to heavy industrial demand for processed items like dry fruits, syrups, jams, and chocolates, private food tech companies are signing **long-term buyback agreements (up to 10 years)** directly at the farm gate.

3. Resource Efficiency and Water Conservation

Water is Rajasthan's most precious commodity, and figs integrate perfectly into conservation frameworks:

Low Water Footprint: Figs require significantly less water compared to traditional cash crops.

Drip Irrigation Compatibility: They adapt seamlessly to micro-irrigation lines. Controlled watering via drip lines protects the root systems and stops fruit splitting during the ripening phase.

4. Expansion of Regional Production Pockets

Initially introduced as trial plots of just 5 hectares, cultivation has expanded aggressively across several specific districts:

Arid Western Zone: Barmer (Gudamalani block), Jodhpur, and Bikaner (Nokha region).

Semi-Arid and Southern Hilly Zones: Sirohi, Udaipur, Pali, Ajmer, Chittorgarh, and Bhilwara.

Fruit Quality of Fig: Fruit quality in fig is determined by physical appearance, taste, nutritional value, and post-harvest characteristics. High-quality figs are soft, sweet, juicy, and free from defects.

1. Physical Quality

- Medium to large fruit size (40–80 g, depending on variety)
- Uniform shape and attractive skin colour
- Thin, tender skin
- Soft, juicy flesh
- Small neck with a closed ostiole (fruit eye), which reduces insect infestation

2. Chemical Quality

- **Total Soluble Solids (TSS):** 18–25 °Brix (indicates sweetness)
- **Total sugars:** 16–22%
- **Acidity:** 0.2–0.4%
- Good sugar-acid balance gives a pleasant flavour
- Rich in pectin, making figs suitable for processing

3. Nutritional Quality

Fresh figs are an excellent source of:

- Dietary fibre Natural sugars (glucose and fructose) Potassium Calcium
- Magnesium Iron Vitamin A Vitamin K Vitamin B6
- Antioxidants such as phenolic compounds and flavonoids

4. Sensory Quality

- Sweet, honey-like flavor
- Pleasant aroma
- Soft texture with a juicy pulp
- Attractive internal flesh colour (pink, red, or amber depending on the variety)

5. Processing Quality

Good-quality figs are suitable for:

- Drying Jam and jelly preparation Syrup and squash
- Bakery products Confectionery

Fruits with high sugar content and firm pulp are preferred for processing.

6. Factors Affecting Fruit Quality

- Variety Climate (warm, dry weather improves sweetness) Soil fertility
- Balanced fertilization Proper irrigation (avoid excess irrigation during ripening)
- Timely harvesting Pest and disease management

7. Quality Standards for Market

- Uniform size and colour Fully ripe but not overripe
- Free from cracks, bruises, insect damage, and diseases
- Clean, fresh appearance High TSS with good flavour
- Good shelf life and transportability

Conclusion

High-quality fig fruits are characterized by high sweetness (18–25 °Brix), soft and juicy flesh, attractive colour, rich nutritional composition, and freedom from physical or pest damage. Proper orchard management, irrigation, nutrition, and harvesting practices are essential for producing premium-quality figs suitable for both fresh consumption and processing.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

FROM FARM WASTE TO FARM WEALTH: TURNING AGRICULTURAL RESIDUES INTO SOIL HEALTH AND CROP PRODUCTIVITY

Article ID: AG-V06-I09-11

K. Monisha[1*], V. Srithar[2] and R.S. Sushma[3]

[123*]PG Student, Department of Agronomy, Faculty of agriculture, Annamalai University, Chidambaram, Tamil Nadu, India

*Corresponding Author: K. Monisha

Abstract

India generates hundreds of million tonnes of crop residue every year, yet a large share of it is still burned in the field or discarded rather than returned to the soil that produced it. This article reviews the major pathways by which agricultural residues, particularly rice straw and other cereal by-products, can be converted from a disposal problem into a productivity asset. In situ incorporation and surface mulching are shown to steadily rebuild soil organic carbon, raise phosphorus availability, buffer soil pH, and improve aggregation and water-holding capacity over repeated seasons, though slow decomposition and short turnaround windows between crops remain practical constraints (Baloch et al., 2025; Butterly et al., 2013; Guo et al., 2018; Hiel et al., 2018). Composting and vermicomposting transform bulky, slow-decomposing residues into a stable, nutrient-rich soil amendment that farmers can apply predictably or sell, while biochar produced by pyrolysis offers a long-lived, carbon-dense amendment that improves nutrient retention and is especially useful on degraded or sandy soils (Agegnehu et al., 2017; Oyege & Balaji Bhaskar, 2023). Residue can also be diverted into bioenergy feedstock, though this pathway competes directly with soil-return uses and must be weighed against the resulting loss of organic matter (Battaglia et al., 2021; Shinde et al., 2022). In the specific context of Tamil Nadu's Cauvery Delta Zone, where mono-cropped rice systems generate large straw volumes under tight cropping windows, composting and mushroom cultivation have been identified as more practical residue outlets than field burning or uneconomical animal feeding (Prasanthkumar & Kannan Vallal, 2018). Rather than treating one method as universally superior, this review

argues that residue management should be matched to the cropping system, the turnaround time available between harvest and the next sowing, and the farmer's access to labour, machinery, and markets, with residue burning treated as a last resort given its documented cost to air quality, soil biology, and human health (Lan et al., 2022; Zhao et al., 2016).

Keywords: Crop residue management, Soil health, Composting, Biochar, Rice straw, Sustainable crop production

Introduction

Agricultural residues, the straw, stubble, husk, and other plant material left over after harvest, have traditionally been viewed by many farmers as waste rather than a resource. Because mechanised harvesting leaves large volumes of residue scattered across the field just as the next crop needs to be sown, open burning has become the fastest and cheapest way to clear land, particularly in intensive cereal systems (Baloch et al., 2025). Yet burning destroys precisely the organic matter and nutrients that the next crop could have used: a tonne of paddy straw carries substantial quantities of nitrogen, phosphorus, potassium, sulphur, and organic carbon, almost all of which is lost to the atmosphere when it is set alight rather than returned to the soil (Fu et al., 2021).

The practice also imposes a measurable public health cost. In north-west India alone, satellite-tracked residue burning has been linked to tens of thousands of premature deaths a year from particulate matter exposure, with a small number of districts responsible for a disproportionate share of the damage (Lan et al., 2022). Against this backdrop, agricultural science has increasingly framed residue management not as a disposal question but as a soil health, input-efficiency, and farm income question: properly managed, the same biomass that pollutes the air when burned can rebuild soil organic carbon, improve nutrient cycling, and generate a saleable product for the farmer (Baloch et al., 2025; Sarkar et al., 2020). This article reviews four broad pathways for converting agricultural residues into soil and economic value, in situ incorporation and mulching, composting and vermicomposting, biochar production, and bioenergy or other value-added uses, and situates these options within the specific constraints of rice-based systems such as Tamil Nadu's Cauvery Delta Zone.

In Situ Incorporation and Mulching

The most direct way to return residue value to the soil is to leave it in the field, either incorporated into the topsoil or retained on the surface as mulch. Incorporation and surface

retention improve soil physical, chemical, and biological properties by supplying organic carbon as the residue decomposes, which in turn promotes aggregate formation, increases porosity, and improves water infiltration and moisture retention relative to fields where residue is removed or burned (Baloch et al., 2025; Fu et al., 2021). These benefits extend to specific chemical properties that matter for long-term fertility: repeated residue return has been shown to raise soil pH under field conditions, buffering against acidification, and to increase available phosphorus and phosphorus-use efficiency in agroecosystems where straw is incorporated over multiple years (Butterly et al., 2013; Guo et al., 2018). A seven-year rotation trial in temperate, loamy soils similarly found that consistent residue management altered soil chemistry and sustained crop production more effectively than residue removal, confirming that the benefits of incorporation compound over time rather than appearing in a single season (Hiel et al., 2018). In degraded or reclaimed soils, conservation-agriculture systems that combine residue retention with reduced tillage have also been shown to improve nutrient availability, illustrating that residue management works best as part of a wider set of conservation practices rather than in isolation (Jat et al., 2018).

The main practical constraint, especially in double- and triple-cropped rice systems, is time: residue must be managed within a narrow window between harvest and the sowing of the next crop, and slow-decomposing, high-carbon residue can temporarily immobilise soil nitrogen if it is incorporated without adequate time or nitrogen supplementation before the next crop is sown. In the Cauvery Delta Zone specifically, the overlap between Kuruvai harvest and Thaladi or Samba planting, often compounded by north-east monsoon rains, leaves very little slack for straw incorporation, which is one reason farmers in the zone have historically defaulted to burning or, where labour allows, feeding straw to livestock (Prasanthkumar & Kannan Vallal, 2018).

Composting and Vermicomposting

Where the cropping calendar does not allow residue to be incorporated directly, composting offers a way to convert the same biomass into a stable, concentrated soil amendment that can be applied on the farmer's own schedule or sold as a marketable product. Aerobic composting and earthworm-based vermicomposting both break down cellulose-rich residue into a humus-like material with a more balanced nutrient profile and a much lower carbon-to-nitrogen ratio than raw straw, reducing the risk of nitrogen immobilisation when the finished compost is

eventually applied. A systematic review of vermicompost use in cereal systems found that it consistently increases nutrient availability, improves soil microbial activity, and supports comparable or higher grain yields relative to unamended soils, while also serving as a base material for humic-acid-rich liquid extracts that can be applied as foliar feeds (Oyege & Balaji Bhaskar, 2023). For farmers in rice-growing tracts such as the Cauvery Delta Zone, composting and mushroom cultivation on straw substrate have been identified as more economically and practically viable outlets for surplus paddy straw than either open burning or straw-based animal feeding, which is often uneconomical and can be detrimental to livestock health when done at scale (Prasanthkumar & Kannan Vallal, 2018). Composting also has an advantage that in situ incorporation lacks: it produces a transportable, storable input, meaning residue generated on one plot, or one farm, can be converted into manure that is applied on a different plot or sold to a neighbouring farmer, turning what would otherwise be a localised disposal problem into a tradable soil-health product.

Biochar: A Longer-Lived Carbon Investment

Pyrolysis, heating crop residue in a low-oxygen environment, converts biomass into biochar, a stable, highly porous, carbon-rich material that persists in soil far longer than raw residue or compost. Because of its porosity and high cation exchange capacity, biochar improves nutrient retention, reduces bulk density, and increases water-holding capacity, benefits that have been documented across a wide range of feedstocks and soil types (Agegnehu et al., 2017). These properties make biochar particularly useful on degraded, sandy, or nutrient-poor soils where retaining applied fertiliser is a bigger constraint than supplying fresh organic matter, and the underlying logic connects directly to a broader finding in soil science: the productive capacity of a cropping system tracks closely with the biological and structural health of its soil, not simply with the nutrients applied in a given season (Xing et al., 2025). Biochar production also offers a route to using residue that is otherwise too fibrous, too dispersed, or too costly to collect for composting, since pyrolysis units can be sized for village- or cluster-level operation and the resulting biochar is compact enough to transport and store economically. Because biochar decomposes far more slowly than compost, its soil-improving effect is best understood as a one-time or infrequent capital investment in soil structure rather than a seasonal nutrient supply, and it is most effective when combined with, rather than substituted for, other nutrient sources.

Bioenergy and Other Value-Added Uses

Beyond direct soil application, crop residue can also be diverted into bioenergy production, whether as a solid fuel, a feedstock for biogas, or, in the case of stover and straw, as an input to biofuel processing. On-farm utilisation reviews have catalogued a wide range of such uses for surplus residue, from energy generation to packaging and industrial raw material, alongside the more familiar routes of composting and direct field return (Shinde et al., 2022). This pathway needs to be weighed carefully, however, because removing residue for bioenergy directly competes with the soil-return uses described above: a review of corn stover and wheat straw removal for biofuel production found that excessive removal reduces soil organic carbon, degrades soil structure, and can ultimately lower crop productivity and increase net greenhouse gas emissions once these soil losses are accounted for (Battaglia et al., 2021). The practical implication is that bioenergy use is best treated as a partial, carefully calibrated outlet for surplus residue rather than a default destination, with enough straw always left on or returned to the field to protect the soil gains that composting, mulching, and biochar are designed to deliver.

Comparative Assessment

None of these pathways is a universal solution; each fits a different point in the trade-off between speed, cost, and durability of benefit. In situ incorporation and mulching require the least handling and no additional infrastructure, but they demand a cropping window that many intensive rice systems, including much of the Cauvery Delta Zone, simply do not have. Composting and vermicomposting require more labour and time but decouple residue management from the sowing calendar entirely, and they produce a saleable input that can generate direct farm income, which is why they have been highlighted as the more practical option for delta rice farmers relative to burning or animal feeding (Prasanthkumar & Kannan Vallal, 2018). Biochar requires the most capital and technical input of the three but delivers the longest-lasting structural benefit and is best suited to soils where nutrient retention, rather than nutrient supply, is the limiting factor. Diverting residue to bioenergy can generate revenue and useful fuel, but only within limits, since over-removal erodes the very soil organic carbon and biological activity that the other pathways are built to protect (Battaglia et al., 2021; Zhao et al., 2016). Burning, by contrast, offers no soil benefit at all: it is fast and requires no investment, but it destroys the organic carbon and nutrients the other pathways are built to capture, while

imposing well-documented air-quality and health costs on surrounding communities (Lan et al., 2022).

Residues as a Complement to, Not a Replacement for, Synthetic Fertilizers

As with animal manures, crop residues are best framed as a complement to synthetic fertilisers rather than a wholesale substitute. Residue-based amendments release nutrients more slowly and less predictably than mineral fertiliser, so they are poorly suited to meeting a crop's peak-demand nutrient requirements on their own; but they consistently improve the soil's underlying capacity to hold and cycle nutrients over time, an effect that synthetic fertiliser alone does not provide (Baloch et al., 2025). Long-term field trials combining residue return with reduced fertiliser rates have shown improvements in soil organic matter and associated biological properties that fertiliser-only management does not replicate (Zhao et al., 2016), while reviews of input-use efficiency argue that residue management should be treated as a core component of nutrient planning rather than an afterthought to it (Sarkar et al., 2020). Integrating residue management, whether through incorporation, compost, or biochar, with a calibrated, reduced rate of chemical fertiliser has therefore been proposed as a more sustainable path than either full substitution or continued reliance on synthetic inputs alone, particularly on soils already showing signs of organic matter decline (Fu et al., 2021).

Conclusion

The evidence reviewed here supports treating crop residue not as waste to be cleared as quickly as possible but as a farm resource whose value depends on how it is managed. Where the cropping calendar allows it, in situ incorporation and mulching offer the simplest route to rebuilding soil organic carbon, raising phosphorus availability, and buffering soil pH over successive seasons (Butterly et al., 2013; Guo et al., 2018; Hiel et al., 2018). Where time is short, as in much of Tamil Nadu's rice-dominated Cauvery Delta Zone, composting and vermicomposting convert the same residue into a marketable, schedule-independent input, and have been specifically identified as a more viable alternative to burning in this cropping system (Prasanthkumar & Kannan Vallal, 2018; Oyege & Balaji Bhaskar, 2023). Biochar offers a further, longer-lived option for degraded or nutrient-poor soils where retention rather than supply is the constraint, and bioenergy use can absorb genuinely surplus residue provided enough biomass is left to protect the soil (Agegnehu et al., 2017; Battaglia et al., 2021). What unites all of these pathways is that they recover value that burning simply destroys, at a measurable cost to

soil fertility, air quality, and public health (Lan et al., 2022). Turning farm waste into farm wealth is therefore less a matter of choosing a single best technology than of matching the available residue-management option to the cropping system, the labour and capital a farmer can access, and the length of the window between one harvest and the next sowing.

References

Agegnehu, G., Srivastava, A. K., & Bird, M. I. (2017). The role of biochar and biochar-compost in improving soil quality and crop performance: A review. Applied Soil Ecology, 119, 156-170.

Baloch, S. B., Ali, S., Bernas, J., Konvalina, P., Naveed, M., Baloch, F. B., Jamali, Z. H., Losak, T., Roubik, H., Ghafoor, A., Mehmood, M., & Mustafa, A. (2025). Crop residue management for soil health and environmental sustainability: A comprehensive review. Journal of Soil Science and Plant Nutrition, 25(3), 7808-7828.

Battaglia, M., Thomason, W., Fike, J. H., Evanylo, G. K., von Cossel, M., Babur, E., & Diatta, A. A. (2021). The broad impacts of corn stover and wheat straw removal for biofuel production on crop productivity, soil health and greenhouse gas emissions: A review. GCB Bioenergy, 13(1), 45-57.

Butterly, C. R., Baldock, J. A., & Tang, C. (2013). The contribution of crop residues to changes in soil pH under field conditions. Plant and Soil, 366, 185-198.

Fu, B., Chen, L., Huang, H., Qu, P., & Wei, Z. (2021). Impacts of crop residues on soil health: A review. Environmental Pollutants and Bioavailability, 33(1), 164-173.

Guo, Z., Liu, H., Hua, K., Wang, D., & He, C. (2018). Long-term straw incorporation benefits the elevation of soil phosphorus availability and use efficiency in the agroecosystem. Spanish Journal of Agricultural Research, 16(3), e1101.

Hiel, M. P., Barbieux, S., Pierreux, J., Olivier, C., Lobet, G., Roisin, C., & Dumont, B. (2018). Impact of crop residue management on crop production and soil chemistry after seven years of crop rotation in temperate climate, loamy soils. PeerJ, 6, e4836.

Jat, H. S., Datta, A., Sharma, P. C., Kumar, V., Yadav, A. K., Choudhary, M., & McDonald, A. (2018). Assessing soil properties and nutrient availability under conservation agriculture practices in a reclaimed sodic soil in cereal-based systems of North-West India. Archives of Agronomy and Soil Science, 64(4), 531-545.

Lan, R., Eastham, S. D., Liu, T., Norford, L. K., & Barrett, S. R. H. (2022). Air quality impacts of crop residue burning in India and mitigation alternatives. Nature Communications, 13, 6537.

Oyege, I., & Balaji Bhaskar, M. S. (2023). Effects of vermicompost on soil and plant health and promoting sustainable agriculture. Soil Systems, 7(4), 101.

Prasanthkumar, K., & Kannan Vallal, S. (2018). Rice residue management for rice based cropping system in Cauvery delta zone - A review. Agricultural Reviews, 39(3), 241-245.

Sarkar, S., Skalicky, M., Hossain, A., Brestic, M., Saha, S., Garai, S., & Brahmachari, K. (2020). Management of crop residues for improving input use efficiency and agricultural sustainability. Sustainability, 12(23), 9808.

Shinde, R., Shahi, D. K., Mahapatra, P., Singh, C. S., Naik, S. K., Thombare, N., & Singh, A. K. (2022). Management of crop residues with special reference to the on-farm utilization methods: A review. Industrial Crops and Products, 181, 114772.

Xing, Y., Wang, X., & Mustafa, A. (2025). Exploring the link between soil health and crop productivity. Ecotoxicology and Environmental Safety, 289, 117703.

Zhao, B., Zhang, J., Yu, Y., Karlen, D. L., & Hao, X. (2016). Crop residue management and fertilization effects on soil organic matter and associated biological properties. Environmental Science and Pollution Research, 23, 17581-17591.

Volume: 06 Issue No: 09

CULTIVATION OF POMEGRANATE IN RAJASTHAN

Article ID: AG-VO6-I09-12

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture, Sri Karan Narendra Agriculture University (SKNAU), Jobner -303329, Rajasthan, India

Introduction

Pomegranate cultivation has transformed parts of the Thar Desert into highly profitable orchards. Over **17,000 hectares** are dedicated to pomegranate farming in Rajasthan, concentrated heavily in arid western districts like **Barmer, Jalore, Balotra, and Jodhpur**. The region produces roughly **156,844 tonnes** annually, turning the state into India's second-largest producer after Maharashtra.

Below is the scientific package of practices optimized for Rajasthan's extreme climate.

Suitable Varieties for Rajasthan :_ Selecting the right variety ensures optimal tolerance to heat waves, drought, and brackish irrigation water.

Bhagwa (Super Bhagwa): The commercial gold standard. Occupies the largest acreage due to its heavy, glossy crimson rind, sweet dark-red arils, soft seeds, and excellent export demand to global markets.

Jalore Seedless: A locally adapted variety selected by CAZRI Jodhpur. Known for medium-to-large round fruits, pinkish arils, high sugar content (TSS 15–16%), and superb heat tolerance.

Ganesh: A popular soft-seeded domestic variety that thrives across semi-arid zones.

Mridula / Phule Arakta: Fast-growing varieties boasting deep-red rinds and highly attractive aril coloration.

Field Preparation and Planting

To safeguard plants against heavy desert winds and intense summer heat, field layouts must follow highly structured steps.

Soil & Climate: It thrives in **well-drained sandy loam or alluvial soils**. Avoid heavy clay soils where water logging can easily damage shallow root zones.

Pit Preparation: Dig pits measuring **1m x 1m x 1m** about a month prior to planting to let solarization disinfect the soil. Fill each pit with a nutritious mix of:

Topsoil mixed with **20–25 kg of well-rotted Farmyard Manure (FYM)**

1 kg of Single Super Phosphate (SSP)

100g of Neem cake to repel soil-borne termites

Spacing: Use a rectangular or square spacing system of **5m x 3m** or **4m x 4m** (roughly 200 to 330 plants per acre)]

Planting Material: Always source certified **tissue culture saplings**. Avoid open air-layering or traditional stem cuttings, as they frequently carry *bacterial blight* pathogens that can destroy the entire plantation.

Bahar Regulation (Flowering Control):

Pomegranates can flower up to three times a year, but allowing continuous fruiting reduces crop quality. In Rajasthan, choosing a specific flowering cycle (Bahar) is essential.

Bahar Cycle	Water Stress Period	Flowering Time	Harvesting Time	Suitability for Rajasthan
Mrig Bahar	May to June	July to August	December to January	**Highly Recommended**. Utilizes monsoon rainfall; fruits mature during cool winter months, minimizing sun scald.
Hasta Bahar	August to September	October to November	March to April	**Good for Drylands**. Produces high-quality, premium priced fruit, but demands reliable winter irrigation.
Ambe Bahar	December to January	February to March	July to September	**Not Recommended**. Fruit sets during peak desert summers, leading to extreme fruit cracking and sun scorching.

To regulate Bahar, completely cut off water for 4–6 weeks until leaves turn yellow and drop off. Prune dead branches, apply fertilizers, and resume drip irrigation to trigger rapid, synchronized female flowering.

Water and Nutrient Management

Precision application keeps plants productive despite low regional rainfalls.

Drip Irrigation: A strict requirement in Rajasthan. It minimizes weed expansion, conserves scarce water resources, and maintains steady moisture to prevent sudden fruit splitting.

Mulching: Laying down **silver-black plastic weed mats** (25–30 microns) prevents soil moisture evaporation, checks weed growth, and reflects light into the lower canopy to produce uniform crimson fruit skins.

Fertilization: Give mature trees (5+ years) an annual breakdown of **600g Nitrogen, 250g Phosphorus, and 250g Potassium**, distributed in split doses through fertigation lines alongside essential micronutrients like Zinc, Boron, and Iron during fruit development.

Crop Protection and Challenges

Fruit Sucking Moth: Active during the evening near harvest. Can be managed by bagging fruits with non-woven bags or hanging light traps.

Bacterial Blight (*Xanthomonas axonopodis*): Characterized by black, oily spots on leaves and L-shaped cracks on fruit. Prevented by spray applications of Streptocycline (0.5g/L) mixed with Copper Oxychloride (2.5g/L).

Fruit Cracking: Occurs during sharp fluctuations in soil moisture or extreme dry heat waves. Maintain uniform drip schedules and spray **Boron (0.2%)** when fruits reach lemon size to strengthen the rinds.

Importance of Pomegranate Farming

1. High Economic Returns

- Pomegranate is a high-value fruit crop that provides better income than many traditional field crops.
- Farmers can earn good profits due to strong domestic and international demand.
- The fruits have premium market prices throughout the year.

2. Suitable for Arid and Semi-Arid Regions

- Pomegranate is drought-tolerant and performs well under low rainfall conditions.
- It is highly suitable for Rajasthan because of its ability to withstand high temperatures and water scarcity.
- It can be successfully cultivated on marginal lands with proper irrigation.

3. Efficient Water Use

- Drip irrigation significantly reduces water consumption.
- Fertigation through drip irrigation improves fertilizer use efficiency.
- Water-use efficiency is much higher compared to many fruit crops.

4. Export Potential

- Indian pomegranates are exported to countries in the Middle East, Europe, and Asia.
- Export-quality fruits fetch higher prices and increase farmers' income.
- The crop contributes to foreign exchange earnings.

5. Nutritional Importance

- Rich source of vitamins (especially Vitamin C and Vitamin K).
- Contains antioxidants such as polyphenols and anthocyanins.
- Good source of dietary fiber, potassium, and other essential minerals.
- Regular consumption supports heart health and boosts immunity.

6. Medicinal Value

- The fruit possesses antioxidant, anti-inflammatory, and antimicrobial properties.
- Juice and peel extracts are used in traditional medicine.
- It may help reduce the risk of cardiovascular diseases and improve overall health.

7. Employment Generation

- Pomegranate cultivation creates employment opportunities in nursery raising, planting, pruning, irrigation, harvesting, grading, packing, and marketing.
- Processing industries also generate rural employment.

8. Value Addition

- **Fruits can be processed into:**
  - Juice Syrup Squash Jam
  - Jelly Anardana (dried arils) Nutraceutical products
- **Value-added products increase farmers' profitability.**

9. Long Productive Life

- A well-managed orchard can remain productive for 20–25 years.
- After establishment, annual maintenance costs are relatively lower compared to the returns.

10. Climate Resilience

- The crop tolerates heat and dry conditions better than many fruit crops.
- It is suitable for climate-resilient horticulture in water-scarce regions.

11. Scope for Integrated Farming

- Farmers can integrate pomegranate orchards with drip irrigation, mulching, beekeeping, and intercropping during the initial years.
- This improves land-use efficiency and farm income.

Importance in Rajasthan

Pomegranate farming has great potential in Rajasthan because:

- It is well adapted to the state's hot and dry climate.
- Drip irrigation helps conserve scarce water resources.
- It offers higher profitability than many conventional crops.
- It supports diversification of agriculture and improves farmers' livelihoods.
- It has strong demand in domestic and export markets.

Fruit Quality of Pomegranate: The market value and export potential of pomegranate are directly determined by its fruit quality. In international and premium domestic trade, fruit quality is divided into external appearance (how it looks to the consumer) and internal sensory traits (how it tastes and feels).

1. External Quality Attributes (Visual Appeal)

External traits dictate consumer preference and grading at the market level.

Fruit Size and Weight: Premium or export-grade fruits typically weigh between **300g to 450g+**. Smaller fruits (under 200g) are relegated to local juice processing.

Skin (Rind) Color: Deep, uniform crimson or ruby-red skin is highly prized. Yellowish-green patches reduce market value.

Rind Smoothness and Gloss: Clean, shiny rinds without blemishes, sun-scald, or thrip marks command the highest prices.

Shape: Perfectly round or slightly crown-shaped fruits are preferred over deformed, asymmetrical shapes.

2. Internal Quality Attributes (Eating Quality)

Internal traits determine eating pleasure and processing suitability.

Aril Color: Consumers prefer deep red to ruby-black arils (like in the *Bhagwa* variety).

Pale pink or white arils are less desirable for table consumption.

Seed Hardness: Soft-seeded (*Mridula, Ganesh*) or "seedless" (*Jalore Seedless*) varieties are highly preferred for fresh eating. Hard woody seeds lower the eating quality.

Juice Content: High-quality table fruit should yield over **45% to 50% juice** by total fruit weight.

3. Chemical and Biochemical Quality Indicators: These parameters are measured scientifically to determine optimal harvest maturity and taste.

Total Soluble Solids (TSS): Measures the sugar concentration, recorded in degrees Brix (°B). Mature, high-quality pomegranates must have a TSS between **15°B to 17°B**.

Titratable Acidity (TA): Measures organic acid content (chiefly citric acid). For a sweet taste, acidity should be low, ideally between **0.5% to 0.7%**.

TSS-to-Acid Ratio: The ultimate metric for taste balance. A ratio between **20:1 and 30:1** provides the perfect sweet-tart flavor profile preferred by consumers.

Antioxidant & Phenolic Content: Pomegranates are prized for health benefits. High levels of anthocyanins, punicalagins, and Vitamin C enhance both health value and natural shelf-life.

Factors That Lower Fruit Quality

Defect	Cause	Impact on Quality
Fruit Cracking	Irregular watering, Boron deficiency, or sudden temperature drops.	Destroys market value; exposes arils to fungal rot.
Sun Scald / Scorching	Intense summer heat and direct sunlight exposure.	Creates brown, leathery patches on the skin, damaging internal arils.
Internal Breakdown	Harvesting over-mature fruit or calcium deficiency.	Arils turn brown, soft, and develop a fermented, alcoholic taste.

Conclusion: Pomegranate farming is an economically profitable, nutritionally valuable, and climate-resilient horticultural enterprise. Its adaptability to arid conditions, efficient use of water, high market demand, and export opportunities make it one of the most promising fruit crops for sustainable agriculture, particularly in Rajasthan and other dry regions of India.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

IMPORTANCE OF BER CULTIVATION IN RAJASTHAN

Article ID: AG-V06-I09-13

***[1]D.L. Bagdi and [2]Purushotam Sharma**

[1]Department of Plant Physiology, S.K.N. College of Agriculture,

[2]Department of Entomology, S.K.N. College of Agriculture,

Jobner, Rajasthan-303329, India

*Corresponding Author: D.L. Bagdi

Introduction

In Rajasthan, ber (Indian jujube or *Ziziphus mauritiana*) cultivation spans over 1,158 hectares with an annual production of approximately 8,853 to 9,869 metric tonnes, serving as a vital drought-hardy fruit crop for arid and semi-arid tracts. Prominent districts actively contributing to this production include Jaipur, Chittorgarh, Hanumangarh, Jodhpur, Barmer, Bharatpur, Alwar, and Sri Ganganagar.

Climate and Soil Requirements

Climate: Thrives in hot, dry desert conditions with temperature tolerances ranging from 15°C to 40°C; highly resistant to drought but sensitive to frost.

Soil: Grows well in a wide range of inferior or marginal soils, including sandy, saline, and alkaline soils, though deep sandy loam or clay loam with good drainage is ideal.

Popular Varieties in Rajasthan

Gola: An early-maturing, round-fruited variety highly popular for arid zones.

Umran: A late-maturing, high-yielding variety producing large, sweet, golden-yellow fruits.

Seb: Named for its apple-like shape and appearance, categorized as a late-season variety.

Thar Bhubhraj: A selection specifically native and adapted to the Bhusavar region of Rajasthan.

Cultivation Practices & Management

Propagation: Best established via vegetative methods such as T-budding or shield budding on

rootstocks for uniform growth.

Spacing: Standard planting distance is maintained at 6 meters × 6 meters under rainfed conditions, or wider depending on irrigation access.

Pruning: Requires heavy annual pruning during May and June since flowers and fruits emerge exclusively on current-season growth.

Yield: Mature trees under proper care yield roughly 80 to 200 kg of fruits per tree annually, while rainfed desert trees average 50 to 80 kg.

Importance of Ber cultivation

Ber cultivation offers excellent economic potential for farmers in Rajasthan's arid regions, though it carries specific management challenges.

Quality of Ber Fruit

The overall quality of **ber fruit (***Ziziphus mauritiana***)** is evaluated by its excellent nutritional profile, crisp physical texture, and high chemical composition of sugars and organic acids. It is widely nicknamed the "poor man's apple" **or** "desert apple" because its nutritional value matches or outperforms apples and oranges at a much lower.

Nutritional Profile & Composition

Vitamin C: Exceptionally rich in ascorbic acid, containing **65 to 235 mg per 100g of pulp**, which easily surpasses the vitamin C concentration of oranges.

Carbohydrates & Sugars: Contains up to **17% carbohydrates** composed of sucrose, glucose, fructose, and galactose, making it an immediate, energy-dense snack.

Protein & Minerals: Outperforms apples in protein (0.8%), phosphorus, and calcium. It also provides essential iron, potassium, and amino acids.

Antioxidants: Packed with healthy bioactive compounds, flavonoids, phenolics, and triterpenic acids that eliminates harmful free radicals.

Physicochemical Quality Traits

Total Soluble Solids (TSS): Varies greatly by variety, commonly ranging from **12.1° Brix to 21.8° Brix**. Higher TSS values signal a distinctly sweeter fruit profile.

Acidity & Taste Ratio: Total acidity spans **0.26% to 0.48%**. The TSS-to-acid ratio directly determines consumer preference; well-balanced ratios offer a highly pleasant, sweet-tart flavor.

Skin & Flesh Texture: Premium ber fruits have smooth, glossy, taut skin with crisp, juicy, and succulent white inner flesh. Over-ripe fruits naturally transition into a soft, spongy, or mealy consistency.

The importance of **ber (*Ziziphus mauritiana*)** spans across economic, nutritional, environmental, and industrial sectors, making it one of the most valuable crops for sustainable dryland agriculture.

Economic & Livelihood Security

Guaranteed Income: Provides dependable cash flow for smallholder farmers in areas where other fruit crops fail due to harsh weather.

Low Production Costs: Requires minimal spending on irrigation, expensive fertilizers, and intensive management compared to crops like pomegranate or citrus.

Employment Generation: Creates local jobs through labor needed for pruning, harvesting, grading, and transporting fruits during the winter dry season.

Nutritional & Health Value

Affordable Nutrition: Earned the title "Poor Man's Apple" because it delivers high-end nutrients at a fraction of the cost of temperate fruits.

Immunity Booster: Rich in Vitamin C (65–235 mg/100g) and antioxidants, which strengthen the immune system and protect cells from damage.

Traditional Medicine: Bark, leaves, and fruits are heavily used in Ayurveda to treat digestive issues, skin infections, insomnia, and fever.

Environmental Sustainability

Combats Desertification: Deep, aggressive taproots bind loose sandy soils, reducing wind and water erosion in desert-prone regions like Rajasthan.

Water-Smart Crop: Enters summer dormancy by shedding leaves during peak heat, conserving scarce groundwater resources.

Afforestation Catalyst: Survives on highly degraded, saline, alkaline, and rocky wastelands, helping to green otherwise barren landscapes.

Industrial & Waste Utilization

Fodder & Lac Culture: Nutrient-rich leaves serve as excellent fodder for goats and sheep. The tree is also a primary host for cultivating lac insects used in shellac industries.

Value-Added Processing: Fruits can be processed commercially into dehydrated candies, powders, juice blends, jams, and traditional herbal wines.

Advantages

Drought Tolerance: Survives on minimal water due to deep taproots and summer dormancy.

Marginal Soil Utilization: Thrives in sandy, saline, alkaline, and nutrient-poor soils common in Rajasthan.

Low Initial Investment: Requires fewer expensive inputs compared to sensitive orchard crops like citrus or pomegranate.

High Financial Returns: Yields up to 100–200 kg per mature tree, ensuring steady income in drylands.

Nutritional Value: Rich in Vitamin C, minerals, and antioxidants, supporting local food security.

Frost Escape: Late winter harvesting allows the crop to avoid peak early-winter frost damage.

Disadvantages

Fruit Fly Vulnerability: Extremely susceptible to the Ber Fruit Fly, which can ruin up to 80% of the harvest if untreated.

Perishable Nature: Fruits ripen quickly and spoil fast, requiring immediate sale or cold storage.

Labor-Intensive Pruning: Requires heavy, mandatory annual pruning in May–June, increasing labor costs.

Thorny Handling: Sharp thorns on traditional varieties make harvesting, pruning, and training difficult.

Bird and Bat Damage: Ripe fruits attract severe damage from birds and bats, requiring costly netting or guarding.

Market Price Fluctuations: Lack of organized processing units leads to sudden price drops during peak harvest seasons.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

IMPORTANCE OF FOLIAR FERTILIZATION TECHNIQUE FOR FARMERS

Article ID: AG-V06-I09-14

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture, Sri Karan Narendra Agriculture University (SKNAU), Jobner -303329, Rajasthan, India

Introduction

Foliar fertilization is a method of supplying essential plant nutrients directly to the leaves by spraying a dilute solution of fertilizers or nutrient formulations onto the foliage. Nutrients are absorbed mainly through the leaf cuticle, stomata, and other epidermal structures and are subsequently transported within the plant. It is particularly useful when nutrients are required rapidly, when root uptake is restricted, or when a crop has a temporary nutrient deficiency.

Importance of Foliar Fertilization in the National Economy

Foliar fertilization can contribute to the national economy through **higher productivity, improved produce quality and more efficient use of fertilizers**.

Major economic contributions

1. Increased agricultural productivity:

Correcting nutrient deficiencies can improve crop growth and yield, increasing farm income.

2. Improved quality of produce:

Appropriate nutrient management can improve fruit size, color, firmness, nutritional quality and marketability.

3. Efficient fertilizer utilization:

Foliar application can deliver relatively small amounts of nutrients directly to the plant, particularly micronutrients.

4. Reduced production losses:

Rapid correction of deficiencies can prevent yield reduction caused by nutrient stress.

5. Support to horticultural industries:

Better nutrition can improve the productivity and quality of fruits, vegetables, flowers and other high-value crops.

6. Improved profitability:

When properly timed and applied, foliar fertilization may provide economic returns through increased yield or quality relative to the cost of application.

7. Food and nutritional security:

Improved crop productivity contributes to a more stable supply of agricultural commodities.

8. Resource conservation:

More targeted nutrient application can help reduce unnecessary fertilizer use and improve overall nutrient management.

Methods of Foliar Fertilization : The general procedure is as follows:

1. **Identify the nutrient requirement**

   Determine the nutrient deficiency or crop requirement through visual symptoms, soil testing, or plant tissue analysis.

2. **Select a suitable fertilizer**

   Common foliar nutrients include:

   i. Nitrogen – urea
   ii. Phosphorus – phosphate formulations
   iii. Potassium – potassium nitrate, potassium sulfate
   iv. Calcium – calcium nitrate/calcium chloride
   v. Magnesium – magnesium sulfate
   vi. Zinc – zinc sulfate or chelated zinc
   vii. Iron – iron chelates
   viii. Boron – boric acid/borax
   ix. Manganese – manganese sulfate

3. **Prepare the spray solution**

Dissolve the required quantity of fertilizer in clean water. Concentration must be appropriate for the crop because excessive concentration may cause leaf scorching.

4. **Use suitable spraying equipment**

   Knapsack sprayers, power sprayers, tractor-mounted sprayers, or specialized foliar application equipment can be used.

5. **Spray uniformly**

   Spray should cover the foliage adequately, preferably on both surfaces where practical, without excessive runoff.

6. **Choose the appropriate time**

   Spraying is generally best during **cooler parts of the day**, such as early morning or late afternoon, when evaporation is lower.

7. **Repeat applications when necessary**

   Several low-concentration applications may be more effective and safer than one highly concentrated spray.

Purpose of Foliar Fertilization: The main purposes are:

i. To correct **nutrient deficiencies quickly**.
ii. To provide nutrients during critical growth stages.
iii. To supplement soil/root fertilization.
iv. To improve plant growth and development.
v. To improve flowering, fruit set and fruit development.
vi. To improve yield and quality of agricultural and horticultural crops.
vii. To provide micronutrients that may be unavailable in the soil.
viii. To improve nutrient use efficiency.
ix. To supply nutrients when root activity is limited by drought, waterlogging, low temperature, or unfavorable soil conditions.
x. To support crop recovery after environmental stress.

4. Importance of Foliar Fertilization

A. Rapid nutrient supply

Leaves can absorb nutrients relatively quickly, making foliar feeding useful for correcting certain deficiencies.

B. Useful during unfavorable soil conditions

When soil pH, moisture, salinity, temperature, or other conditions restrict root nutrient uptake, foliar application can provide an alternative route.

C. Improved nutrient-use efficiency

Small quantities of nutrients can be applied directly to the plant rather than applying large amounts to the soil.

D. Important for micronutrients

Foliar spraying is particularly useful for supplying micronutrients such as **Zn, Fe, B, Mn and Cu** when deficiencies occur.

E. Better crop productivity

Properly timed foliar fertilization can contribute to improved growth, yield, fruit set, seed development and produce quality.

F. Important in horticulture

It is widely useful in fruit, vegetable, ornamental and plantation crops where precise nutrient management is important.

Merits of Foliar Fertilization

i. **Rapid correction of nutrient deficiency.**
ii. Nutrients are applied directly to the plant.
iii. Requires relatively **small quantities of fertilizer**.
iv. Can improve nutrient-use efficiency.
v. Particularly effective for **micronutrient application**.
vi. Useful when root absorption is restricted.
vii. Can be combined with some crop-protection sprays when compatibility is confirmed.
viii. Useful at critical crop-growth stages.
ix. Can improve crop yield and quality when properly managed.
x. Reduces dependence on soil application for some specific nutrient requirements.

Demerits of Foliar Fertilization

i. **Leaf burn (phytotoxicity)** can occur if concentration is too high.
ii. Only limited quantities of many nutrients can be supplied through leaves.
iii. It generally **cannot completely replace soil fertilization** for major nutrient requirements.
iv. Rain shortly after spraying can wash nutrients from leaves.
v. High temperature and strong sunlight may increase the risk of leaf injury.
vi. Uniform spraying requires appropriate equipment and technique.
vii. Repeated applications may increase labor and operational costs.

viii. Effectiveness can vary with crop species, leaf age and environmental conditions.

ix. Some fertilizer combinations may be chemically incompatible.

x. Foliar application may not provide sufficient nutrients for crops with very high nutrient demand.

Precautions in Foliar Fertilization: The following precautions are essential:

1. **Always follow the recommended concentration** for the crop and fertilizer.
2. Do not use excessively concentrated solutions.
3. Conduct a **small-area test spray** when using a new formulation or mixture.
4. Avoid spraying during very **hot, dry or windy conditions**.
5. Prefer early morning or late afternoon applications.
6. Avoid spraying immediately before rainfall.
7. Use **clean water** for preparing spray solutions.
8. Ensure that the fertilizer is completely dissolved before spraying.
9. Maintain proper spray coverage without excessive runoff.
10. Check compatibility before mixing fertilizers with pesticides or other products.
11. Avoid incompatible mixtures that may cause precipitation or leaf injury.
12. Use appropriate personal protective equipment such as gloves, protective clothing and eye protection.
13. Keep spray equipment clean and properly calibrated.
14. Avoid applying foliar fertilizers to severely stressed or wilted plants unless the product recommendation specifically permits it.
15. Follow the manufacturer's label and locally recommended agricultural practices.

Conclusion

Foliar fertilization is an important supplementary nutrient-management technique in modern agriculture and horticulture. It provides nutrients directly through the foliage and is especially valuable for rapid correction of micronutrient deficiencies and for supplying nutrients during periods when root uptake is restricted. However, it should generally be considered a supplement to sound soil and root nutrition rather than a complete replacement for basal fertilization. Correct concentration, suitable timing, uniform application and proper precautions are essential for obtaining maximum benefit without causing leaf injury.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

SOIL–PLANT–ATMOSPHERE CONTINUUM IN RELATION TO WEATHER

Article ID: AG-VO6-I09-15

Dr. Sachin S. Chinchorkar

Associate Professor, Polytechnic in Agricultural Engineering, Anand Agricultural University, Dahod, Gujarat, India

1. Introduction

Plants do not live independently of their surroundings. Their growth and productivity depend on continuous interactions among **soil, plants and the atmosphere**. This interconnected system is known as the **Soil–Plant–Atmosphere Continuum (SPAC)**. It describes how water, energy, nutrients and gases move from the soil through plant roots and stems to leaves and finally to the atmosphere.

Weather strongly influences these processes. Temperature, rainfall, humidity, solar radiation, wind and atmospheric dryness can change soil moisture, plant water uptake, transpiration, photosynthesis and nutrient absorption. Understanding SPAC is therefore important for efficient irrigation, crop management, drought monitoring and climate-resilient agriculture [1–4].

2. What is the Soil–Plant–Atmosphere Continuum?

The SPAC can be visualized as a continuous pathway:

Soil → Roots → Xylem → Leaves → Atmosphere

Water enters the soil mainly through rainfall or irrigation. Roots absorb this water and transport it through the xylem to leaves. A major part of the absorbed water is subsequently released into the atmosphere through tiny openings called **stomata**. This process is called **transpiration**.

The movement of water is controlled by differences in **water potential**. Water generally moves from areas of higher water potential toward areas of lower water potential. Soil hydraulic

properties, root characteristics, xylem conductivity and atmospheric demand together determine how efficiently water moves through this continuum [1,4].

Modern land-surface models increasingly incorporate plant hydraulic characteristics to represent this process more realistically [1]. The GEOSPACE framework is another example of an approach designed to represent the different components of the soil–plant–atmosphere system in an integrated manner [2].

3. Weather: The Main Driver

Weather determines the strength of the atmospheric demand for water and strongly affects the soil and plant components of SPAC.

Temperature

Temperature affects almost every biological and physical process in the continuum. Increasing temperature raises the capacity of air to hold water vapour and can increase atmospheric demand for transpiration. Temperature also affects root activity, nutrient availability, photosynthesis and crop development.

Very high temperatures, especially when accompanied by dry soil, can cause excessive water loss and thermal stress. During heatwaves, stomata may close to conserve water, but this also reduces transpiration and photosynthesis.

Rainfall and Humidity

Rainfall is the principal natural source of soil-water recharge. The amount, intensity and duration of rainfall determine how much water infiltrates into the root zone. Heavy rainfall may produce runoff, while moderate rainfall can effectively replenish soil moisture.

Humidity has an opposite effect on atmospheric water demand. High humidity reduces the difference in water-vapour concentration between leaves and air and therefore generally reduces transpiration. Low humidity increases atmospheric demand and can accelerate plant water loss.

Vapor Pressure Deficit

Vapor Pressure Deficit (VPD) is one of the most useful indicators of atmospheric dryness. It represents how strongly the atmosphere demands water vapour from plant leaves.

When VPD increases, transpiration can initially increase if sufficient soil water is available. However, under very high VPD, plants may close their stomata to protect themselves

from excessive water loss. This reduces transpiration and photosynthesis and can increase leaf temperature [3,5].

Recent research shows that plant response to atmospheric drought and soil-water drought can differ considerably. Thus, monitoring only soil moisture may not always provide a complete picture of plant water stress [5].

Solar Radiation

Solar radiation supplies the energy required for photosynthesis and also drives evaporation and transpiration. When soil moisture is adequate, a considerable portion of available energy is used for evaporation and transpiration, helping to cool leaves and the soil surface.

When soil becomes dry, evaporative cooling decreases. Consequently, more energy is converted into sensible heat, causing increases in soil and leaf temperature. This creates a feedback between **soil moisture, temperature and atmospheric water demand**.

Wind

Wind affects the thin layer of air surrounding leaves, known as the **boundary layer**. Stronger winds generally remove humid air from around leaves and increase heat and water-vapour transfer. Therefore, wind can increase transpiration even when other weather conditions remain unchanged.

Canopy structure, leaf size and plant density determine how strongly wind influences individual leaves and the entire crop canopy.

4. Soil: The Water Reservoir

Soil acts as the main water reservoir for most agricultural plants. Its ability to store and supply water depends on **texture, structure, organic matter, water content and hydraulic conductivity**.

Sandy soils generally drain rapidly and have relatively low water-holding capacity. Clay-rich soils can retain more water but may release it slowly to plants. Soil structure also determines the size and connectivity of pores through which water and air move.

The relationship between soil water content and soil water potential is particularly important. As soil dries, the energy required by roots to extract water increases. At sufficiently low soil-water availability, roots cannot supply enough water to meet atmospheric demand [6,7].

Recent global research has demonstrated that soil texture plays a major role in determining the degree of water limitation experienced by ecosystems [7].

5. Roots, Xylem and Stomata

- Plants regulate water movement through several interconnected mechanisms.
- **Roots** determine where and how deeply a plant can obtain water. Deep and well-distributed root systems can access water from larger volumes of soil and may provide greater resistance to drought.
- Water then moves through the **xylem**, the plant's internal water-conducting system. Hydraulic conductivity of roots and xylem determines how easily water can move toward the leaves. Under severe water stress, the xylem may become vulnerable to cavitation or hydraulic failure, disrupting water transport [1,8].
- At the leaf surface, **stomata** act as adjustable gates. They open to allow carbon dioxide to enter for photosynthesis and permit water vapour to leave. Under high VPD or declining soil moisture, stomata may close to conserve water [3,9].
- Thus, plants constantly balance two competing requirements: **absorbing carbon dioxide for growth and conserving water for survival**.

6. Evapotranspiration: The Link with Weather

The total transfer of water from land to the atmosphere is called **evapotranspiration (ET)**. It consists mainly of:

1. **Soil evaporation**
2. **Plant transpiration**
3. **Water loss from intercepted rainfall on plant surfaces**

The proportion of these components changes with weather and soil conditions. After rainfall, soil evaporation may dominate. As the canopy develops, transpiration can become the major component.

Accurate estimation of ET is important for irrigation scheduling, water-resource management and assessment of crop water stress. Weather variables such as temperature, solar radiation, humidity and wind are major controls of ET [10].

7. Drought and Heat Stress

Drought occurs when water availability becomes insufficient for normal ecosystem or crop functioning. It may result from inadequate rainfall, high temperature, high atmospheric demand, or a combination of these factors.

During drought, soil moisture declines and plant water uptake becomes increasingly difficult. Stomatal closure reduces transpiration and photosynthesis. Prolonged drought may eventually cause leaf senescence, reduced growth and yield losses.

Importantly, **atmospheric drought can occur even when soil moisture is not yet extremely low**. High temperature and VPD can increase plant water demand rapidly, causing physiological stress before severe soil drying occurs [5,9].

Heatwaves are particularly damaging when they coincide with dry soil and high VPD. Flowering and reproductive stages are often highly sensitive to extreme temperatures, making timely irrigation and weather-based crop management particularly important.

8. Importance for Agriculture

Understanding SPAC has direct applications in modern agriculture. Farmers can use weather information together with soil moisture observations to improve irrigation decisions. Instead of irrigating only according to a fixed calendar, irrigation can be adjusted according to **soil-water availability and atmospheric demand**.

Research has shown that sustainable irrigation can be improved by considering both soil-water supply and atmospheric evaporative demand [11]. This approach can reduce unnecessary water use while maintaining crop productivity.

SPAC knowledge is also useful for drought forecasting, crop modelling, precision agriculture and climate-change adaptation.

9. Measurement and Modern Technology

Today, SPAC processes can be monitored using **soil-moisture sensors, weather stations, sap-flow measurements, thermal cameras, satellites and remote sensing**. Satellite observations can provide information on vegetation condition, land-surface temperature and water stress over large areas.

Combining ground observations with remote sensing and physically based models provides a powerful approach for understanding soil–plant–atmosphere interactions at field, regional and national scales [1,2,12].

10. Conclusion

The Soil–Plant–Atmosphere Continuum provides a simple but powerful way to understand how **soil, plants and weather function as one interconnected system**. Soil supplies water and nutrients, roots absorb them, xylem transports water to leaves, and the atmosphere controls the demand for water through temperature, humidity, VPD, radiation and wind.

Weather variability can therefore alter the entire pathway—from soil moisture and root water uptake to transpiration, photosynthesis and crop productivity. Future agriculture will increasingly require integration of **soil moisture observations, weather forecasting, plant responses, remote sensing and modelling**.

A better understanding of SPAC can help farmers use water more efficiently, manage drought and heat stress, improve irrigation scheduling and build agricultural systems that are more resilient to changing weather and climate.

References

1. Allon, J., Vuichard, N., Ottl, C., Tuzet, A., Luyssaert, S., Cuntz, M., Limousin, J., Kempf, J., & Peylin, P. (2025). Plant hydraulic architecture for a mechanistic representation of soil-plant-atmosphere water transfer in the land surface model ORCHIDEE (r9107). *Journal of Advances in Modeling Earth Systems*. https://doi.org/10.1029/2024MS004869
2. D'Amato, C., Tubini, N., & Rigon, R. (2025). A component-based modular treatment of the soil-plant-atmosphere continuum: The GEOSPACE framework (v.1.2.9). *Geoscientific Model Development*, *18*, 7321–7357.
3. Koehler, T., Wankmüller, F. J., Sadok, W., & Carminati, A. (2023). Transpiration response to soil drying versus increasing vapor pressure deficit in crops: Physical and physiological mechanisms and key plant traits. *Journal of Experimental Botany*, *74*(11), 3287–3300.
4. Bonan, G., Williams, M., Fisher, R., & Oleson, K. (2014). Modeling stomatal conductance in the earth system: Linking leaf water-use efficiency and water transport along the soil-plant-atmosphere continuum. *Geoscientific Model Development, 7*, 2193–2222.

5. Berauer, B., Steppuhn, A., & Schweiger, A. (2024). The multidimensionality of plant drought stress: The relative importance of edaphic and atmospheric drought. *Plant, Cell & Environment*. https://doi.org/10.1111/pce.15012
6. Meusburger, K., Trotsiuk, V., Schmidt-Walter, P., et al. (2022). Soil-plant interactions modulated water availability of Swiss forests during the 2015 and 2018 droughts. *Global Change Biology*, *28*(10), 3156–3170.
7. Wankmüller, F. J., Delval, L., Lehmann, P., et al. (2024). Global influence of soil texture on ecosystem water limitation. *Nature, 634*, 329–335.
8. Deng, J., Wan, L., Bao, Y., Yu, M., & Jia, Q. (2024). Seasonal variations in hydraulic regulation of whole-tree transpiration in Mongolian pine plantations: Insights from semiarid deserts in Northern China. *Forests*, *15*(8), 1367.
9. Manandhar, A., Pichaco, J., & McAdam, S. (2024). Abscisic acid increase correlates with the soil water threshold of transpiration decline during drought. *Plant, Cell & Environment, 47*(8), 3357–3369.
10. Yu, Z., Jia, W., Zhang, M., Zhang, F., Lan, X., Zhang, Y., & Luo, H. (2024). Evapotranspiration variation of soil-plant-atmosphere continuum in subalpine scrubland of Qilian Mountains in China. *Hydrological Processes, 38*(5), e15156.
11. Zhang, J., Guan, K., Peng, B., et al. (2021). Sustainable irrigation based on co-regulation of soil water supply and atmospheric evaporative demand. *Nature Communications, 12*, 5254.
12. Wang, Y., Zeng, Y., Alidoost, F., et al. (2025). A physically consistent dataset of water-energy-carbon fluxes across the soil-plant-atmosphere continuum. *Scientific Data, 12*, 41.

Volume: 06 Issue No: 09

SUSTAINABLE FISHERIES MANAGEMENT OF FLOODPLAIN WETLANDS IN INDIA

Article ID: AG-V06-I09-16

R. G. Sasikumar

Department of Fisheries Biology and Resource Management

Fisheries College and Research Institute, Thoothukudi, Tamil Nadu, India

Abstract

Floodplain wetlands are important inland fishery resources in India, supporting biodiversity, fisheries and the livelihoods of local communities. Their management depends largely on hydrological connectivity with rivers. Open wetlands are primarily managed through capture fisheries and protection of natural recruitment, whereas closed wetlands are suitable for culture-based fisheries involving stocking and recapture. Integrated approaches, including pen and cage culture, species enhancement and habitat improvement, can increase fish production. Sustainable management requires the conservation of indigenous fishes, maintenance of river–wetland connectivity, regulation of fishing practices, control of aquatic weeds and participatory management. These measures can enhance fish production while ensuring biodiversity conservation and long-term livelihood security.

Fisheries Management of Floodplain Wetlands

Wetlands in India provide important ecosystem services and support the livelihoods of thousands of people through fishing, collection of edible plants, agriculture, irrigation, water transport and other economic activities, while also supporting rich biological diversity (Sugunan, 2011; Lianthuamluaia & Das, 2021). Most wetlands are directly or indirectly associated with river systems. Among these, floodplain wetlands associated with major river systems cover an estimated 3.54 lakh ha and constitute important inland fishery resources, particularly in the Ganga and Brahmaputra basins (Sugunan, 2011; Sarkar & Borah, 2018).

Capture Fishery for Open Wetlands

Floodplain wetlands that retain their connection with the parent river for a reasonably

long period generally have relatively better hydrological connectivity and natural fish recruitment. Such wetlands can be managed primarily under a capture fisheries approach. The principal management strategy is to promote natural recruitment by conserving brooders and juveniles.

Important management measures include the identification and protection of breeding and nursery grounds, conservation of brood stock and juveniles, regulation of fishing during breeding periods and maintenance of free migration routes between wetlands and rivers (Sugunan, 2011). River–wetland connectivity is particularly important because it influences fish migration, recruitment, biodiversity and fisheries productivity (Sarkar & Borah, 2018; Lianthuamluaia & Das, 2021).

Culture-Based Fishery for Closed Wetlands

Closed floodplain wetlands, or wetlands that remain connected with rivers only for a short period, are frequently affected by excessive macrophyte growth, habitat degradation and poor natural recruitment. Under such conditions, management is more similar to culture-based fisheries, where fish production is enhanced through stocking and recapture. The basic strategy involves stocking suitable species or advanced fingerlings and harvesting them after a defined growth period. These wetlands may support good growth because of their high natural productivity and the availability of diverse food niches (Sugunan, 2011). Proper stocking density, species composition and stocking size are essential for achieving optimum production (Lianthuamluaia & Das, 2021).

Capture and Culture-Based Fisheries

Some floodplain wetlands can be managed through a combination of capture fisheries and culture-based or enclosure fisheries. Under this system, marginal areas may be cordoned off for fish culture in ponds or pens, while the central open-water area is retained for capture fisheries. A series of small enclosures can be established along the wetland periphery and used for fish culture or seed rearing. Some enclosures may function as nurseries for producing seed required for aquaculture and stocking in the main wetland. When culture-based fisheries are practised, connecting channels may be provided with wire screens or other suitable structures to reduce the escape of stocked fishes, while sluice gates can regulate water inflow and outflow (Sugunan, 2011).

Integrated Management

Integrated wetland management involves combining agriculture, aquaculture and fisheries with biodiversity conservation. One portion of the wetland may be developed for agriculture and aquaculture, whereas the remaining area can be managed for capture and culture-based fisheries. The different functional zones may be separated using dikes, while canals and suitable water-control structures can regulate water movement. The central marshy area may be retained as a natural habitat for birds and other aquatic organisms. However, modifications to wetland hydrology should be undertaken cautiously because the long-term impacts of large-scale development on hydrodynamics, biological productivity and ecosystem functioning may be significant (Sarkar & Borah, 2018; Lianthuamluaia & Das, 2021).

Species Options

Species management is an important component of floodplain wetland fisheries management. Species selection and stock enhancement should be based on habitat characteristics, natural recruitment, food availability, biodiversity considerations and market demand.

Indian Major Carps

The principal Indian major carps used for stock enhancement are catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*). Where natural recruitment is absent or inadequate, stocking with these fast-growing species can be an effective option for improving fish production (Sugunan, 2011). The stocking ratio and density should be determined according to the availability of natural food resources, including plankton, benthos and detritus, so that different ecological niches can be efficiently utilized.

Indigenous Fishes

It is not necessary to develop all floodplain wetlands exclusively as carp-based fisheries. Conservation and enhancement of indigenous fish species are equally important because natural populations of several native species have declined in many Indian floodplain wetlands due to habitat degradation, altered hydrology, overexploitation and other anthropogenic pressures (Sarkar & Borah, 2018; Lianthuamluaia & Das, 2021). Important indigenous fishes include *Anabas testudineus*, *Clarias batrachus*, *Ompok* spp., murrels, *Amblypharyngodon mola*, *Gudusia chapra* and species of *Puntius* (Sugunan, 2011). Although the biomass yield of some indigenous

fishes may be lower than that of major carps, their higher market value and contribution to biodiversity conservation can compensate for lower production.

Ornamental Fishes

Floodplain wetlands also contain numerous species with ornamental fish potential. Surveys conducted by CIFRI identified 45 species belonging to 16 families in the floodplain wetlands of Assam and 63 species belonging to 23 families in West Bengal with potential for aquarium keeping. Examples include *Gagata cenia*, *Brachydanio* spp., *Danio dangila*, *Nandus nandus*, *Badis badis*, *Oreichthys cosuatis*, *Puntius sophore*, *P. conchonius*, *Colisa fasciatus* and *C. sota*. Several species, including *Puntius sophore*, *P. conchonius*, *Colisa fasciatus* and *C. sota*, have also been successfully bred under captive conditions (Sugunan, 2011).

Production Enhancement Through Enclosure Systems

Pens

Pen culture in the marginal areas of floodplain wetlands has been demonstrated as an effective method for increasing fish and prawn production and generating additional income for wetland-dependent fishers. CIFRI investigations have demonstrated the potential of enclosure or pen culture as a relatively low-cost technology suitable for floodplain wetland ecosystems. A production of 1,308 kg ha^{-1} of the giant freshwater prawn *Macrobrachium rosenbergii* within four months and a return on investment of 29.5% were reported from pen-culture trials. Locally available and relatively inexpensive materials such as bamboo, canes and wooden poles can be used for constructing pens.

Species Used

The species commonly recommended for mixed carp culture include *Catla catla*, *Hypophthalmichthys molitrix*, *Labeo rohita* and *Cirrhinus mrigala*. In mixed culture involving carps and prawns, the giant freshwater prawn *Macrobrachium rosenbergii* can be incorporated as an additional component. A representative species composition reported for mixed culture is *C. catla* (20%), *H. molitrix* (15%), *L. rohita* (20%) and *C. mrigala* (45%). In suitable mixed-culture systems, *C. mrigala* may be partly or completely replaced by *M. rosenbergii*.

Production Estimates

Field trials reported that carp culture in pens could produce approximately 4,000–5,000 kg ha^{-1} $year^{-1}$ under favourable management conditions (Sugunan, 2011). In mixed carp–prawn culture, estimated production was 2,000–2,500 kg ha^{-1} $year^{-1}$ for carps and 500–800 kg ha^{-1}

year^{-1} for prawns. Under monoculture of *Macrobrachium rosenbergii*, an average production of approximately 1,300 kg ha^{-1} during a four-month culture period was reported. These estimates may vary considerably depending on wetland productivity, stocking density, water quality, seed quality and management practices.

Cages

Cage-based seed rearing can also be used as a production-enhancement strategy in floodplain wetlands. Earlier trials involving *Labeo gonius* and *L. bata* reported that fry attained the targeted size of approximately 10 cm and 10 g within 90 days without supplementary feeding under suitable conditions. Fry have been reported to attain fingerling size of approximately 10 cm and 12–28 g within two months, with survival rates of 68–77% at a stocking density of 30 fry m^{-2}. Under suitable conditions, up to three crops per year may be obtained from cage-based seed rearing. However, cage culture technologies for floodplain wetlands require further refinement and evaluation under different ecological and socioeconomic conditions.

Environmental Enhancement

Environmental enhancement refers to improving the nutrient status and biological productivity of water through selective management interventions, including carefully regulated fertilizer application. Although fertilization is a common practice in intensive aquaculture, its application in natural floodplain wetlands requires careful ecological consideration. Uncontrolled nutrient inputs can contribute to eutrophication, excessive algal growth, oxygen depletion and changes in aquatic community structure. Therefore, any environmental enhancement programme should be based on scientific assessment of water quality and regular monitoring of ecological impacts (Sarkar & Borah, 2018; Lianthuamluaia & Das, 2021).

Issues in the Management of Wetlands

The management of floodplain wetlands involves not only resource-related issues but also broader livelihood, institutional and governance challenges. These wetlands are generally extensive, multiple-use ecosystems that may not be under the effective control of a single stakeholder, resulting in competing uses and potential degradation of the resource. In many cases, fishers do not have direct ownership or long-term control over wetland resources and may operate under lease arrangements, paying rent or a share of their production to the agencies or individuals controlling the water body. Inadequate reinvestment of lease revenue into fisheries development can further limit sustainable management. Major management issues include

habitat degradation, loss of connectivity, excessive aquatic weeds, overfishing, capture of juveniles, declining indigenous fish populations, pollution, agricultural runoff and weak institutional coordination (Sarkar & Borah, 2018; Lianthuamluaia & Das, 2021).

Common Guidelines for the Management of Wetlands

Wetland fisheries management should adopt an integrated, participatory and ecosystem-based approach. The following measures are commonly recommended.

- Wetlands should be managed, wherever feasible, through cooperative or community-based institutions with equitable participation of fishers.
- Different activities occurring in privately and government-owned wetlands should be regularly monitored.
- Fishing effort should be increased or reduced according to the productivity and stock status of the wetland.
- Closed seasons should be observed to protect spawning fish and brood stock.
- Restrictions on the minimum size of capture should be strictly implemented to prevent excessive removal of juveniles.
- Fishing gears and mesh sizes should be regulated to avoid indiscriminate exploitation.
- Selective augmentation or stocking should be undertaken only after evaluating natural recruitment, species composition and carrying capacity.
- Connecting channels should be desilted where necessary to restore hydrological connectivity.
- Appropriate sluice gates and water-control structures may be provided while ensuring that essential fish migration is not unduly obstructed.
- Wetland shorelines should be stabilized through suitable vegetation or plantation, and runoff carrying sediments and agricultural pollutants should be intercepted or minimized.
- GIS-based inventories should be developed to document wetland resources, fisheries potential, biodiversity and culture-based fishery opportunities.
- Excessive macrophyte infestation should be controlled or removed, where ecologically appropriate, to restore open-water habitat and improve fisheries productivity.
- Indigenous fish diversity and critical breeding and nursery habitats should be protected as integral components of fisheries management (Sarkar & Borah, 2018; Barman et al., 2023).

References

Barman, R. C., Kar, D., & Dana, S. S. (2023). Effect of predictive factors on sustainable development and management of freshwater wetland fisheries. *Indian Journal of Fisheries*.

Lianthuamluaia, & Das, B. K. (2021). Status, potential, prospects, and issues of floodplain wetland fisheries in India: Synthesis and review for sustainable management. *Reviews in Fisheries Science & Aquaculture, 29*(1), 1–32.

Sarkar, U. K., & Borah, B. C. (2018). Floodplain wetland fisheries of India: With special reference to impact of climate change. *Wetlands Ecology and Management, 26*, 1–17.

Sugunan, V. V. (2011). Inland fisheries resource enhancement and conservation in India. In *Inland Fisheries Resource Enhancement and Conservation in Asia*. FAO Regional Office for Asia and the Pacific.

Volume: 06 Issue No: 09

THE PSYCHOLOGY AND PHYSIOLOGY OF STRESS IN FISH

Article ID: AG-V06-I09-17

Atul Kumar Singh[1], Vineet Anand[1]*, Pankaj Kumar Singh[1] and Debashis Mohanta[1]

[1]ICAR-Central Institute of Fisheries Education, Mumbai, M.H., India

*Corresponding Author: Vineet Anand

Introduction

Stress is a central biological problem for fish because their internal condition is tightly linked to the surrounding water. Temperature, oxygen, salinity, pollutants, crowding, handling, social conflict, and predators can all change rapidly, and fish must detect these changes and adjust their behavior and physiology. Stress is therefore not simply a harmful state. In its short-term form, it is an adaptive response that mobilizes energy and helps an animal survive a challenge. Problems arise when a stressor is too intense, repeated too often, or persists long enough that the fish cannot restore physiological stability (Wendelaar Bonga, 1997; Barton, 2002).

Modern fish-stress research increasingly treats stress as an integrated process involving perception, behavior, the brain, endocrine organs, metabolism, and immunity. This broader view is important because two fish exposed to the same physical condition may not respond identically. Prior experience, social status, genetics and individual coping style can influence the interpretation of a challenge and the degree of activation of the stress response (Øverli et al., 2007; Schreck & Tort, 2016). Thus, understanding stress in fish requires attention to both psychology—meaning perception, learning, motivation, and behavioral coping—and physiology.

What Counts as a Stressor?

A stressor is any internal or external challenge that threatens, or is perceived to threaten, normal biological function. Stressors in the natural environment include hypoxia, rapid changes in temperature, altered salinity, lack of food, predator exposure, competition and social aggression. In aquaculture additional stressors include high stocking density, netting, grading,

transport, vaccination, noise, artificial lighting, poor water quality and sudden changes in husbandry. Chemical stressors such as ammonia, nitrite, heavy metals and pesticides can also interfere with normal function (Barton, 2002; Pankhurst, 2011).

Stressors are often described as acute or chronic. Acute stress is brief in duration such as capture by a net or sudden exposure to a predator. Chronic stress is stress that continues for days or weeks, such as bad water quality, repeated aggression or long-term crowding. This difference is important because a short stress response may be adaptive but chronic activation may have energetic and physiological costs. Fish can also habituate to predictable non-threatening disturbances but unpredictable or uncontrollable events can be highly disruptive (Schreck & Tort, 2016).

Perception, Behavior and Coping

The best way to understand the psychological aspect of fish stress is by studying observable neurobehavioral processes rather than assuming that fish are experiencing stress in the same way as humans. Sensory systems detect a change and, when the brain judges its biological significance, initiate a stress response. The same event can therefore produce different responses depending on whether it is novel, familiar, avoidable, associated with danger, or linked to a previous experience.

Behavior often provides the earliest visible evidence of stress. Fish may increase escape swimming, freeze, hide, alter schooling, change depth or tank position, increase ventilation, reduce feeding, or become unusually aggressive or inactive. Because behavior reflects how an animal is interacting with and responding to its environment, it is now widely used as a practical component of fish-welfare assessment (Martins et al., 2012). Reduced appetite is especially important: it can be both an immediate coping response and, when prolonged, a route through which stress depresses growth.

Individual fish also show consistent differences in stress-coping style. Research in rainbow trout selected for high or low cortisol responsiveness has linked endocrine reactivity with differences in aggression, locomotion, feeding recovery, social dominance, and conditioned behavior. These patterns helped establish the distinction between relatively proactive and reactive coping styles. In particular contexts, proactive individuals tend to display more active behavioral responses and lower hypothalamus-pituitary-interrenal reactivity, while reactive individuals may show more behavioral flexibility but stronger cortisol responses (Øverli et al.,

2007). These are not rigid personalities, but responses depend on species, context, and prior experience.

Cognition is also important. Fish are able to learn associations, remember threatening situations and alter future behavior. Stress can influence attention, learning, and decision-making through brain monoamines such as serotonin, dopamine, and noradrenaline, as well as through corticosteroid signaling. Consequently, behavioral recovery after a disturbance may reveal more than simple physical exhaustion; it can reflect the way an individual processes and responds to a challenging environment (Øverli et al., 2007; Ellis et al., 2012).

The Physiological Stress Machinery

The physiological stress response is usually described in primary, secondary, and tertiary stages. The primary response involves rapid activation of neuroendocrine systems. Two major pathways are particularly important. 1st, Severe or sudden challenges can cause the release of catecholamines, especially adrenaline and noradrenaline, from the sympathetic and chromaffin tissue. These hormones mediate immediate cardiovascular and respiratory changes and are involved in the mobilization of metabolic fuel (Perry & Bernier, 1999). 2nd, The main corticosteroid response in teleost fish is the hypothalamus-pituitary-interrenal (HPI) axis.

The HPI axis sends stress signals to hypothalamus which secretes corticotropin-releasing hormone or factor. This stimulates the pituitary to release adrenocorticotropic hormone (ACTH), which in turn acts on interrenal cells (mostly in the head-kidney) to cause the release of cortisol. Cortisol is the major glucocorticoid in most teleosts and is one of the most widely measured indicators of acute stress (Wendelaar Bonga, 1997; Mommsen et al., 1999).

Cortisol helps the fish meet increased energetic demand by altering carbohydrate, protein, and lipid metabolism and by supporting functions such as osmoregulation. Secondary responses therefore include changes in blood glucose and lactate, ion balance, oxygen transport, ventilation, cardiac function, and cellular stress proteins. These changes are adaptive in the short term because they redirect resources toward immediate survival (Mommsen et al., 1999; Barton, 2002).

Importantly, cortisol should not be interpreted as a simple "bad welfare" hormone. Cortisol naturally varies among species, individuals, life stages, and environmental conditions, and a temporary increase can be entirely appropriate. Ellis et al. (2012) pointed out that information about cortisol is most meaningful when combined with information about behavior,

context, and other physiological markers. The timing of sampling is also crucial because capture itself can rapidly elevate stress hormones (Pankhurst, 2011).

When Adaptation Becomes Costly

If stress continues, the adaptive response can become biologically expensive. Energy spent coping with disturbance is energy that cannot be fully devoted to growth, tissue repair, reproduction or immune defense. Chronic stress can result in decreased feed intake and growth efficiency, disruption of osmoregulation and metabolic imbalance (Sadoul & Vijayan, 2016). It may also impact reproduction by disrupting the brain-pituitary-gonad axis and altering the endocrine signals that regulate maturation and spawning (Schreck, 2010).

The immune system is closely linked with the stress system. Short-term stress can temporarily boost some aspects of innate immunity, but long-term or repeated stress typically dampens immune functions and can raise the risk of disease (Tort, 2011). This helps explain why outbreaks of infection in aquaculture are often associated with crowding, handling, poor water quality, or other husbandry stressors rather than with pathogen exposure alone.

At the whole-animal level, these effects are called tertiary stress responses. They include depressed growth, reduced reproductive performance, behavioral abnormalities, poorer disease resistance and, in severe cases, mortality (Barton, 2002). Chronic stress may also produce a condition of increased allostatic load: the fish continues to spend biological resources maintaining stability under challenge instead of returning to an efficient resting state (Schreck & Tort, 2016).

An Integrated View of Fish Health and Welfare

No single measurement can fully describe stress. Plasma cortisol is valuable, but it is most informative when combined with variables such as glucose or lactate, ion balance, ventilation, growth, immune indicators, and direct observations of feeding, aggression, exploration, and recovery behavior. The shift from single biomarkers to multi-level assessment is exemplified by novel methods such as gene expression, non-invasive cortisol matrices and integrated molecular profiles (Balasch & Tort, 2019).

This integrated perspective has practical value to aquaculture. Managing stress effectively doesn’t mean eliminating all challenges. Fish require normal environmental stimulation and have evolved mechanisms to cope with short-term disturbances. The goal is to reduce severe, prolonged, and unpredictable stress while providing water quality, stocking

conditions, feeding schedules, shelter or enrichment, and handling procedures appropriate for the species and life stage. Because species and individuals differ substantially, welfare thresholds should not be generalized without biological validation.

Conclusion

Stress in fish is an integrated response that connects perception and behavior with neural, endocrine, metabolic, and immune mechanisms. First, a fish detects and interprets a challenge, then adjusts its behavior and activates rapid catecholamine pathways and the slower HPI-cortisol system. These responses are essential for survival when challenges are brief, but they become costly when activation is excessive or prolonged. Chronic stress can compromise appetite, growth, immunity, reproduction, and overall welfare.

The most useful scientific approach therefore combines psychological and physiological evidence. Behavioral changes show how the fish are responding to the stressor, while hormonal and metabolic measures show how the body is responding internally. In aquaculture, conservation and experimental biology, it is especially important to recognize this two-way relationship because effective management is not only about keeping fish alive, but about keeping conditions in which they can regulate themselves, recover from challenges and perform normal biological functions.

References

Balasch, J. C., & Tort, L. (2019). Netting the stress responses in fish. *Frontiers in Endocrinology, 10*, 62. https://doi.org/10.3389/fendo.2019.00062

Barton, B. A. (2002). Stress in fishes: A diversity of responses with particular reference to changes in circulating corticosteroids. *Integrative and Comparative Biology, 42*(3), 517-525. https://doi.org/10.1093/icb/42.3.517

Ellis, T., Yildiz, H. Y., López-Olmeda, J., Spedicato, M. T., Tort, L., Øverli, Ø., & Martins, C. I. M. (2012). Cortisol and finfish welfare. *Fish Physiology and Biochemistry, 38*(1), 163-188. https://doi.org/10.1007/s10695-011-9568-y

Martins, C. I. M., Galhardo, L., Noble, C., Damsgård, B., Spedicato, M. T., Zupa, W., Beauchaud, M., Kulczykowska, E., Massabuau, J.-C., Carter, T., Planellas, S. R., & Kristiansen, T. (2012). Behavioural indicators of welfare in farmed fish. *Fish Physiology and Biochemistry, 38*(1), 17-41. https://doi.org/10.1007/s10695-011-9518-8

Mommsen, T. P., Vijayan, M. M., & Moon, T. W. (1999). Cortisol in teleosts: Dynamics, mechanisms of action, and metabolic regulation. *Reviews in Fish Biology and Fisheries, 9*, 211-268. https://doi.org/10.1023/A:1008924418720

Øverli, Ø., Sørensen, C., Pulman, K. G. T., Pottinger, T. G., Korzan, W., Summers, C. H., & Nilsson, G. E. (2007). Evolutionary background for stress-coping styles: Relationships between physiological, behavioral, and cognitive traits in non-mammalian vertebrates. *Neuroscience & Biobehavioral Reviews, 31*(3), 396-412. https://doi.org/10.1016/j.neubiorev.2006.10.006

Pankhurst, N. W. (2011). The endocrinology of stress in fish: An environmental perspective. *General and Comparative Endocrinology, 170*(2), 265-275. https://doi.org/10.1016/j.ygcen.2010.07.017

Perry, S. F., & Bernier, N. J. (1999). The acute humoral adrenergic stress response in fish: Facts and fiction. *Aquaculture, 177*(1-4), 285-295. https://doi.org/10.1016/S0044-8486(99)00092-7

Sadoul, B., & Vijayan, M. M. (2016). Stress and growth. In C. B. Schreck, L. Tort, A. P. Farrell, & C. J. Brauner (Eds.), *Biology of Stress in Fish* (Fish Physiology, Vol. 35, pp. 167-205). Academic Press. https://doi.org/10.1016/B978-0-12-802728-8.00005-9

Schreck, C. B. (2010). Stress and fish reproduction: The roles of allostasis and hormesis. *General and Comparative Endocrinology, 165*(3), 549-556. https://doi.org/10.1016/j.ygcen.2009.07.004

Schreck, C. B., & Tort, L. (2016). The concept of stress in fish. In C. B. Schreck, L. Tort, A. P. Farrell, & C. J. Brauner (Eds.), *Biology of Stress in Fish* (Fish Physiology, Vol. 35, pp. 1-34). Academic Press. https://doi.org/10.1016/B978-0-12-802728-8.00001-1

Tort, L. (2011). Stress and immune modulation in fish. *Developmental & Comparative Immunology, 35*(12), 1366-1375. https://doi.org/10.1016/j.dci.2011.07.002

Wendelaar Bonga, S. E. (1997). The stress response in fish. *Physiological Reviews, 77*(3), 591-625. https://doi.org/10.1152/physrev.1997.77.3.591

Volume: 06 Issue No: 09

WEATHER-BASED CROP MANAGEMENT FOR SUSTAINABLE CROP PRODUCTION

Article ID: AG-V06-I09-18

Sachin S Chinchorkar

Associate Professor, Polytechnic In Agricultural Engineering, Anand Agricultural University, Muvaliya Farm, Dahod-389160, Gujarat State, India

Abstract

Agricultural production is highly dependent on weather conditions such as rainfall, temperature, relative humidity, solar radiation and wind. Increasing weather variability, irregular rainfall, droughts, heat waves, floods and unseasonal rainfall are creating significant challenges for sustainable crop production. **Weather-based crop management (WBCM)** provides a scientific approach for improving farm decisions by integrating real-time weather observations, short- and medium-range forecasts, seasonal climate information, crop growth stages and soil conditions. It supports timely decisions related to sowing, irrigation, fertilizer application, pest and disease management, intercultural operations and harvesting. Recent research highlights that linking weather and climate information services with climate-smart agricultural practices can improve agricultural water management and support the adoption of location-specific technologies. The integration of weather information with remote sensing, Internet of Things (IoT), artificial intelligence and digital advisory systems can further improve the precision and timeliness of crop management. Weather-based crop management therefore has considerable potential to increase productivity, improve resource-use efficiency, reduce weather-related losses and strengthen the resilience of farming systems.

Keywords: Weather-based crop management, sustainable agriculture, climate-smart agriculture, weather forecasting, crop production, irrigation management, precision agriculture, climate resilience.

1. Introduction

Weather is one of the most important factors determining crop growth, development and yield. Rainfall controls soil-water availability, while temperature, humidity, solar radiation and wind influence crop evapotranspiration, flowering, disease development and harvesting conditions. Traditionally, farmers have relied heavily on fixed cropping calendars and previous experience. However, increasing climate variability has made such approaches less reliable.

Climate-smart agriculture aims to sustainably increase productivity, strengthen resilience to climate change and, where possible, reduce greenhouse-gas emissions. In this context, weather-based crop management provides an important bridge between meteorological information and practical farm decisions.

2. Concept of Weather-Based Crop Management

Weather-based crop management refers to the use of **current and forecasted weather information together with crop, soil and farm conditions to make timely agricultural decisions**.

The basic approach can be represented as:

Weather observation → Forecast → Crop/soil assessment → Management decision → Farm operation → Monitoring

Important weather parameters include rainfall, temperature, relative humidity, solar radiation, wind speed and evapotranspiration.

The effectiveness of weather information increases considerably when it is converted into an actionable recommendation rather than being supplied to farmers as raw data. A recent review found clear links between weather and climate information services and climate-smart practices, particularly for drought, rainfall distribution, temperature and agricultural water management.

3. Applications in Sustainable Crop Production

3.1 Weather-based sowing

Rainfall forecasts and soil-moisture information can help determine suitable sowing windows. Timely sowing improves germination and crop establishment and can reduce the need for re-sowing. Seasonal weather information can also assist in selecting suitable crops and varieties according to expected rainfall and temperature conditions.

3.2 Irrigation management

Weather-based irrigation scheduling can improve water-use efficiency. Crop water requirements are influenced by temperature, solar radiation, humidity, wind and rainfall. Using evapotranspiration estimates and rainfall forecasts, irrigation can be applied according to actual crop requirements instead of following a fixed schedule.

This can reduce unnecessary irrigation, pumping costs and water losses while maintaining crop productivity. Recent research emphasizes the importance of connecting weather and climate information services with agricultural water management.

3.3 Fertilizer management

Weather forecasts can help determine suitable periods for fertilizer application. Applying nitrogen immediately before heavy rainfall may increase nutrient losses through leaching and runoff. Therefore, fertilizer application can be synchronized with crop growth stage, soil nutrient status and expected weather conditions. This approach can improve nutrient-use efficiency and reduce environmental pollution.

3.4 Pest and disease management

Temperature, humidity and rainfall strongly influence pest populations and disease development. Weather-based forecasting can identify periods of high disease or pest risk and support field scouting and need-based control measures. This reduces unnecessary pesticide applications and supports integrated pest management.

3.5 Management of extreme weather

Weather forecasts provide opportunities for preventive action against drought, heat waves, heavy rainfall and strong winds. Farmers may adjust irrigation, improve drainage, protect crops, modify harvesting schedules or select suitable varieties according to anticipated conditions.

The importance of such preparedness is increasing as extreme weather events increasingly affect agricultural production. Recent agricultural assessments also highlight the contribution of precision agriculture, improved irrigation and drought-tolerant varieties to reducing weather-related production risks.

4. Role of Modern Technologies

The effectiveness of weather-based crop management can be increased through **IoT sensors, remote sensing, artificial intelligence, drones and mobile-based agricultural**

advisories. Soil-moisture sensors can provide field-level information, while satellites can monitor crop stress and vegetation conditions.

Artificial intelligence and machine-learning models can combine weather, soil and crop information to generate location-specific recommendations. Recent research has demonstrated the potential of deep-learning-based weather forecasting and agricultural recommendation systems for providing crop recommendations and extreme-weather alerts.

High-resolution satellite and reanalysis rainfall information also offers opportunities for improving localized climate services, particularly in rainfed farming regions where ground weather observations are limited.

5. Challenges

Despite its potential, several challenges remain. Weather forecasts contain uncertainty, particularly over longer periods. Farmers may also have limited access to localized weather information, digital technologies and technical training. Therefore, weather advisories should be **simple, timely, affordable and location-specific**.

Strong collaboration among meteorological agencies, agricultural universities, extension agencies, technology providers and farmers is necessary for successful implementation.

Conclusion

Weather-based crop management is an important pathway towards **productive, resource-efficient and climate-resilient agriculture**. Instead of treating weather as an uncontrollable risk, farmers can use weather information as a management tool for making timely decisions on sowing, irrigation, fertilization, crop protection and harvesting. Its integration with climate-smart practices can improve water and nutrient-use efficiency, reduce avoidable crop losses and strengthen resilience to climatic variability.

The future of sustainable crop production will increasingly depend on the integration of **weather forecasting, crop science, soil information, remote sensing, IoT and artificial intelligence**. However, technology alone is not sufficient. The greatest impact will come when advanced weather information is converted into simple, field-specific and farmer-friendly advisories. Thus, weather-based crop management should be promoted as an essential component of sustainable and climate-resilient agricultural development.

References

Mabhaudhi, T., Dirwai, T. L., Taguta, C., et al. (2025). *Linking weather and climate information services (WCIS) to Climate-Smart Agriculture (CSA) practices*. **Climate Services, 37, 100529**.

Zheng, H., Ma, W., & He, Q. (2024). *Climate-smart agricultural practices for enhanced farm productivity, income, resilience, and greenhouse gas mitigation: A comprehensive review*. **Mitigation and Adaptation Strategies for Global Change, 29, 28**.

Vaja, R., & Srivastava, A. (2024). *Climate-smart agriculture for sustainable development: A review*. **Current Advances in Agricultural Sciences, 15**, 261–265.

Zubair, M., Salim, M. S., Rahman, M. M. I., et al. (2024). *Agricultural Recommendation System based on Deep Learning: A Multivariate Weather Forecasting Approach*.

FAO/CGIAR. *Climate-Smart Agriculture and Climate Information Services*.

Volume: 06 Issue No: 09

SMART RICE FARMING: INTEGRATING DIRECT-SEEDED RICE WITH DRONE TECHNOLOGY

Article ID: AG-V06-I09-19

Surya K.[1] and Arockia Infant Paul R[2*]

[1]Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore - 641003, Tamil Nadu, India

[2]International Rice Research Institute, New Delhi, India

*Corresponding Author : Arockia Infant Paul R[2]

Abstract

Rice is one of the most important food crops in the world and plays a major role in ensuring food and nutritional security. However, conventional puddled transplanted rice requires large amounts of water, labour and energy, while increasing production costs and contributing to greenhouse gas emissions. Direct-seeded rice (DSR) offers an alternative production system in which rice seeds are sown directly into the field, eliminating the need for raising seedlings and manual transplanting. Although DSR can save labour, water and time, its success depends on precise land preparation, timely sowing, effective weed management, nutrient application and efficient crop monitoring. In this context, drone technology offers new opportunities for precision management of DSR fields. Unmanned aerial vehicles equipped with cameras and sensors can support field scouting, crop establishment assessment, weed identification, nutrient and water stress monitoring, pesticide application and crop surveillance. The integration of DSR with drone-based technologies can improve the timeliness and precision of field operations while reducing unnecessary input use. However, limitations related to equipment cost, technical skills, battery life, weather conditions, regulatory requirements and accessibility need to be addressed. Combining agronomic knowledge with digital technologies can make rice production more resource-efficient, climate-smart and economically viable. This article discusses the potential of integrating direct-seeded rice with drone technology and highlights its role in developing the next generation of smart rice farming.

Keywords: Direct-seeded rice, drones, precision agriculture, unmanned aerial vehicles, smart farming, crop monitoring, weed management, rice production

Introduction

Rice is a staple food for more than half of the world's population and is an important component of food security in many Asian countries. India is one of the world's major rice-producing countries, and rice cultivation supports millions of farming households. However, rice production is facing several challenges, including increasing labour costs, declining water availability, climate variability, rising input prices and the need to reduce greenhouse gas emissions. The traditional method of rice establishment involves raising seedlings in a nursery, puddling the main field and transplanting young seedlings. Although this system is well established, it is highly labour-intensive and requires considerable quantities of water. The shortage and increasing cost of agricultural labour have made transplanting particularly difficult in many rice-growing regions (Surya *et al*., 2025).

Direct-seeded rice (DSR) provides an alternative approach. Instead of transplanting seedlings, rice seeds are directly sown in the main field. This reduces several labour-intensive operations and can shorten the crop establishment period. DSR can also reduce water use associated with nursery raising and puddling and may provide opportunities for more efficient resource management. However, DSR is not simply a change from transplanting to seed sowing. Successful DSR requires careful management from field preparation to harvest. Weed competition is one of the major constraints because weeds emerge along with the rice crop. Uneven crop establishment, improper sowing depth, moisture stress, nutrient imbalance and pest incidence can also affect yield (Sree *et al*., 2026).

This is where digital agriculture can make a difference. Drone technology is emerging as a useful tool for rapid and precise monitoring of agricultural fields. Drones can capture high-resolution images, identify spatial variation within fields and, in some cases, deliver inputs directly to crops. When integrated with DSR, drones can help farmers move from blanket field management towards targeted and timely interventions. Thus, the combination of direct seeding and drone-based precision agriculture represents an important step towards smart, efficient and climate-resilient rice farming.

Direct-seeded rice: A smart alternative to transplanted rice

Direct-seeded rice refers to a rice establishment system in which seeds are sown directly

into the main field rather than transplanting seedlings raised in a nursery. Depending on soil type, climate, water availability and farm machinery, DSR can be established through dry seeding, wet seeding or other direct-seeding methods. The major attraction of DSR is the reduction in labour requirements. In transplanted rice, several operations are involved: nursery preparation, seedling maintenance, puddling, uprooting seedlings, transportation and transplanting. DSR eliminates many of these operations. This can reduce production costs and enable farmers to complete crop establishment more quickly (Paul et al., 2025a).

Another important advantage is water management. Conventional transplanted rice generally requires puddling and standing water during establishment. In DSR, the absence of puddling and the possibility of maintaining appropriate soil moisture rather than continuous flooding can improve water-use efficiency. The reduction in standing water can also influence methane emissions, making appropriately managed DSR a potentially climate-smart establishment method. DSR also provides greater flexibility in crop establishment. With appropriate machinery, large areas can be sown rapidly, allowing farmers to establish the crop within the optimum sowing window. Timely establishment is particularly important under changing climatic conditions, where delayed operations can expose crops to high temperatures, drought or unexpected rainfall (Konappan *et al*., 2025). However, DSR has its own management challenges. The most important is weed management. In transplanted rice, the established rice seedlings initially have a competitive advantage over weeds. In DSR, both rice and weeds emerge from the soil around the same time. Therefore, weeds can compete strongly for water, nutrients, light and space.

Other challenges include achieving uniform germination, maintaining adequate soil moisture, selecting suitable varieties, ensuring proper sowing depth and managing nutrients efficiently. These challenges highlight the need for precise field monitoring. This is where drone technology can complement DSR. Instead of relying entirely on manual field inspection, farmers can use aerial imagery to observe crop establishment, identify problem areas and monitor changes across the field.

Role of drone technology in DSR

Drones, also called unmanned aerial vehicles (UAVs), are remotely operated or autonomous flying platforms that can carry cameras and agricultural sensors. Their ability to capture high-resolution images from above provides a different perspective compared with

conventional ground-based field observations. In DSR, drone technology can support several stages of crop production.

Crop establishment monitoring

Uniform crop establishment is critical in DSR. Poor germination may occur because of inadequate soil moisture, improper seed placement, soil crusting, pests or uneven field conditions. Drone images can provide a rapid overview of large fields and help identify areas with poor crop establishment. Instead of walking through the entire field, farmers or agricultural professionals can use aerial images to locate areas requiring closer ground-level inspection. This makes field scouting faster and more systematic (Paul *et al.*, 2025b).

Weed monitoring

Weed management is one of the most important applications of drone technology in DSR. Since weeds often emerge together with rice, timely identification is essential. High-resolution RGB images and advanced sensor-based systems can potentially distinguish crop and weed patterns based on differences in colour, shape, canopy structure and spatial distribution. With appropriate image-processing and artificial intelligence techniques, weed-infested patches can be mapped. Such information can support site-specific weed management, where control measures are concentrated in areas with significant weed infestation rather than applying inputs uniformly across the entire field (Paul *et al*., 2025a).

Crop health and stress detection

Healthy rice plants have characteristic canopy characteristics that can be detected using aerial imagery. Changes in plant colour, canopy density and vegetation indices can provide indications of crop stress. Multispectral cameras can capture information beyond the visible spectrum. Vegetation indices such as the Normalized Difference Vegetation Index (NDVI) can be used to assess relative differences in crop vigour.

$$\mathbf{NDVI = (NIR - Red) / (NIR + Red)}$$

where NIR represents near-infrared reflectance and Red represents red-band reflectance. Repeated drone flights can generate crop growth maps and help identify areas where crop performance is declining. However, drone-derived information should ideally be validated through field observations before making management decisions.

Water stress monitoring

Water availability is particularly important in DSR because the crop is established

without transplanting into a puddled and continuously flooded field. Uneven soil moisture can lead to poor germination and irregular crop growth. Drone imagery can help identify spatial variation in crop vigour associated with water stress. When combined with field-level soil and weather information, these observations can support more efficient irrigation scheduling and identification of water-stressed zones.

Nutrient management

Nutrient deficiencies can create visible changes in crop growth and canopy characteristics. Drone-based imagery may help identify areas with poor crop vigour associated with nutrient stress. In the future, combining drone imagery with machine learning and field-based nutrient measurements could support variable-rate nutrient management. Rather than applying the same quantity of fertilizer throughout a field, nutrients could potentially be applied according to crop requirement and spatial variability.

Drone-based field operations and crop management

The real potential of drones in DSR goes beyond photography, extending from monitoring to management. Agricultural drones equipped with spray systems can apply selected crop protection products over rice fields, offering rapid coverage without requiring people or ground machinery to move through standing or wet crops. However, effective drone spraying depends on factors such as spray volume, droplet size, flight height, wind speed, nozzle characteristics and product label requirements, as unsuitable conditions may cause spray drift or poor coverage. At the same time, drone-based field scouting can provide a rapid overview of large DSR fields and allow images to be collected periodically from crop establishment to maturity, helping identify abnormal areas that require closer ground-level inspection (Paul *et al*., 2024a).

Drone imagery can also be converted into digital maps showing crop vigour, gaps, weed patches and other spatial patterns and integrated with GPS-based field information. For example, when a particular area shows poor crop growth, farmers can inspect that zone to determine whether the cause is weeds, nutrient deficiency, water stress, pests or soil-related problems rather than treating the entire field uniformly (Paul *et al*., 2024b). The next major step is the integration of drones with artificial intelligence (AI) and machine learning, which can help identify weeds, classify crop growth stages, detect disease symptoms and recognize abnormal crop patterns. Thus, a future DSR field could function as a digital production system in which drone

observations are converted into images, AI analyses the images, problems are identified, field conditions are verified and targeted interventions are implemented. Such integration can make crop monitoring more proactive, improve the speed of decision-making and potentially reduce unnecessary input use, while ensuring that drones complement rather than replace sound agronomic knowledge. The advantages of drone technology integration with DSR mentioned in figure 1.

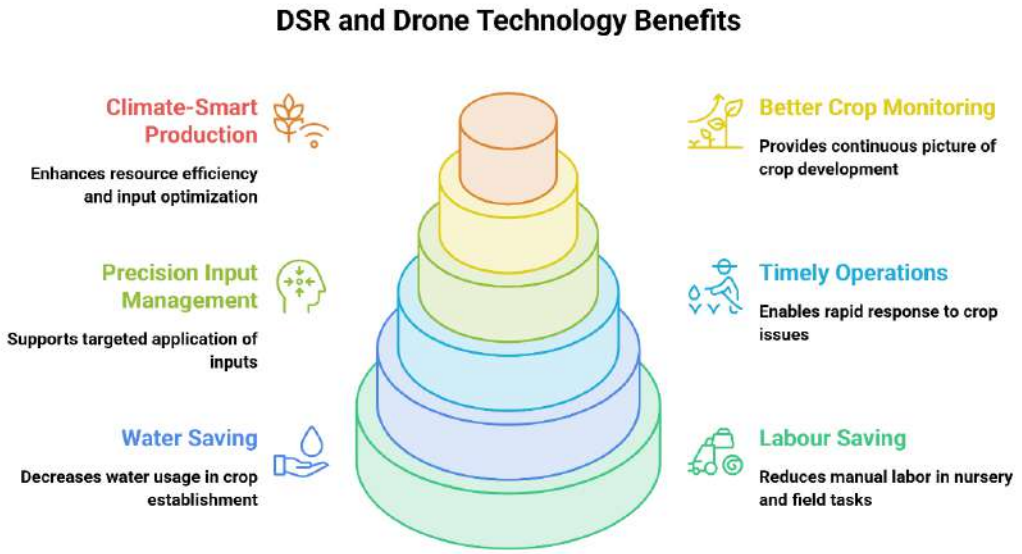


Figure 1. The benefits of integration of drone technology on direct seeded rice

Summary

Direct-seeded rice offers a promising alternative to conventional transplanted rice by reducing the need for nursery raising, puddling and manual transplanting. It can save labour and time and provide opportunities for improved water and resource management. However, successful DSR requires careful attention to crop establishment, weed management, irrigation, nutrients and crop protection. Drone technology can complement DSR by providing rapid field monitoring and supporting precision management. Drones can be used for crop establishment assessment, weed mapping, crop-health monitoring, water-stress detection, nutrient-stress assessment, field scouting and selected spraying operations. The greatest benefit is achieved when drone observations are converted into practical field decisions. The integration of drone imagery, artificial intelligence, GPS, sensors and ground-based observations can enable farmers to identify problems early and apply interventions where they are actually required.

Conclusion

The future of rice farming will depend not only on producing more rice but also on producing it with less water, less labour, fewer unnecessary inputs and greater precision. Direct-seeded rice provides an important pathway towards this goal, while drone technology provides a powerful digital tool for monitoring and managing the crop. The integration of DSR and drones represents a shift from conventional field management towards smart, site-specific and data-driven rice production. Drones can help farmers see what is happening across the field, identify problem areas and respond more quickly. When combined with sound agronomic practices, this technology can improve resource-use efficiency and support sustainable rice production.

However, technology alone cannot solve every challenge. Farmer training, affordable access to drone services, reliable advisory systems, field validation, appropriate regulations and locally adapted technologies are essential. The most successful model will be one in which farmer experience and agronomic science are strengthened, not replaced, by digital technologies. In the coming years, the rice field may no longer be viewed simply as a plot of land requiring uniform management. Instead, it can become a smart field, where every part of the crop is monitored, analysed and managed according to its actual needs. In this transition, direct-seeded rice and drone technology can work together to build a more efficient, profitable and climate-resilient future for rice farming.

References

Konappan, S., Ramanujam, K., Saitheja, V., Subramanian, S., Govindan, S. K., Ettiyagounder, P., Ponnusamy, J., Muthaiyan, G., Mylesamy, G., Infant Paul, R. A., & Selvakumar, G. (2025). Polyhalite as a next generation chloride free multi-nutrient fertilizer for sustainable agriculture–review. *Journal of Plant Nutrition*, *48*(20), 3784–3814. https://doi.org/10.1080/01904167.2025.2523539

Paul, R. A. I., Arthanari, P. M., Pazhanivelan, S., Kavitha, R., & Djanaguiraman, M. (2024b). UAV-based herbicide application for efficient weed management in direct-seeded rice. *Agricultural Science Digest*, *44*(2), 295–300. https://doi.org/10.18805/ag.D-5826

Paul, R. A. I., Arthanari, P. M., Peramaiyan, P., Kumar, V., Bagavathiannan, M., & Surya, K. (2025). Comparative analysis of UAV and electric backpack sprayers for herbicide efficacy and crop-weed nutrient dynamics in direct-seeded rice. *Journal of Agriculture and Food Research, 23*, 102307. https://doi.org/10.1016/j.jafr.2025.102307

Paul, R. A. I., Arthanari, P. M., Peramaiyan, P., Kumar, V., Bagavathiannan, M., & Sabarivasan, R. (2025). UAV-based herbicide application for efficient weed control and resource savings in direct-seeded rice. *Crop Protection, 190,* 107129. https://doi.org/10.1016/j.cropro.2025.107129

Paul, R. A. I., Palanisamy, M. A., Peramaiyan, P., Kumar, V., Bagavathiannan, M., Gurjar, B., Vijayakumar, S., Djanaguiraman, M., Pazhanivelan, S., & Ramasamy, K. (2024a). Spray volume optimization with UAV-based herbicide application for effective droplet deposition and weed control in direct-seeded rice. *Frontiers in Agronomy, 6*, 1491842. https://doi.org/10.3389/fagro.2024.1491842

Sree, Y. S., Karthikeyan, R., Boomiraj, K., Djanaguiraman, M., Thirunavukkarasu, M., Paul, R. A. I., Jeevan, N., & Prasanna, J. (2026). Assessment of different sowing windows and crop geometry on fodder yield, quality and economics of dual-purpose sorghum (*Sorghum bicolor*). *The Indian Journal of Agricultural Sciences, 96*(1), 63–69. https://doi.org/10.56093/ijas.v96i1.165132

Surya, K., Sornam, G., Asritha, M., Paul, R. A. I., Easwaran, C., Sri, B. K., Sathasivam, B., Saitheja, V., Narayanan, J., Ramalingam, S. P., Parameswari, E., Ponnusamy, J., & Ramanujam, K. (2025). Unraveling approaches of silica nanoparticles for next-generation in agricultural sustainability. *Frontiers in Sustainable Food Systems, 9,* 1677788. https://doi.org/10.3389/fsufs.2025.1677788

Volume: 06 Issue No: 09

VERMIWASH AND COW-BASED FORMULATIONS FOR ENHANCING CROP GROWTH AND SOIL BIOLOGICAL ACTIVITY

Article ID: AG-V06-I09-20

Monika Ray

Scientist (Agronomy), AICRP on Linseed, Regional Research and Technology Transfer Station (RRTTS), Keonjhar, Odisha University of Agriculture and Technology (OUAT), Bhubaneswar, Odisha, India

Abstract

Sustainable agriculture increasingly relies on biological inputs that improve crop productivity while maintaining soil health and environmental quality. Vermiwash and cow-based formulations such as Jeevamrut, Beejamrut, Panchagavya, and cow urine extracts have gained attention as low-cost, eco-friendly alternatives to synthetic agrochemicals. These bio-inputs contain beneficial microorganisms, plant growth-promoting substances, enzymes, nutrients, and bioactive compounds that enhance seed germination, vegetative growth, nutrient uptake, and soil biological activity. Vermiwash, a liquid extract obtained from vermicompost systems, is rich in plant growth regulators, micronutrients, and microbial metabolites, whereas cow-based formulations supply diverse microbial populations and organic compounds that stimulate rhizosphere processes. This article reviews the composition, preparation methods, mechanisms of action, agronomic benefits, effects on soil biological properties, limitations, and future prospects of vermiwash and cow-based formulations for sustainable crop production.

Keywords: Vermiwash, Jeevamrut, Panchagavya, cow urine, soil biological activity, organic farming, natural farming, plant growth promotion.

Introduction

Intensive agriculture has substantially increased crop yields, but excessive dependence on chemical fertilizers and pesticides has led to declining soil organic matter, reduced microbial diversity, nutrient imbalances, and environmental pollution. These concerns have stimulated interest in biological and organic nutrient management strategies that support long-term soil

fertility and ecological sustainability.

Among the various bio-inputs used in organic and natural farming, vermiwash and cow-based formulations occupy a prominent position due to their simplicity, affordability, and compatibility with smallholder farming systems. Traditional Indian agricultural practices have long utilized cow-derived products, while modern vermitechnology has demonstrated the potential of earthworm-based systems to generate nutrient-rich liquid extracts and compost.

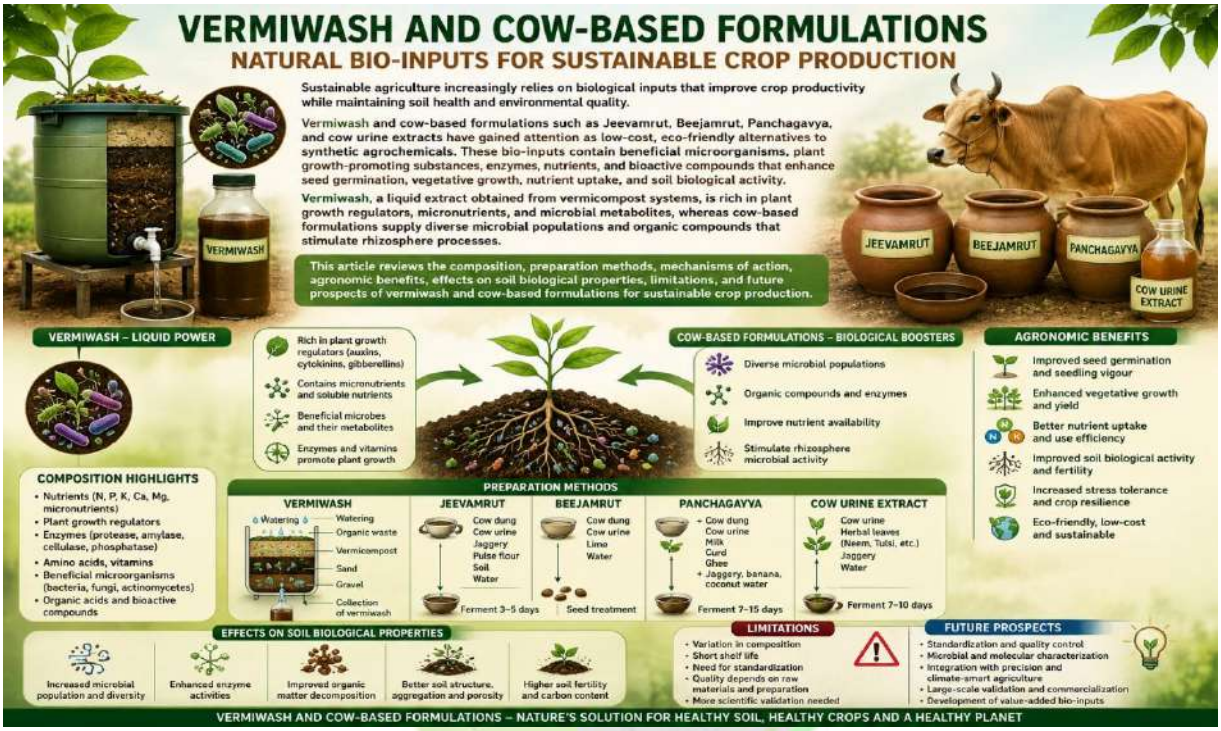


Figure 1. Natural Farming Inputs: Vermiwash, Jeevamrut, Beejamrut, and Panchagavya for Sustainable Agriculture

These formulations are increasingly being evaluated for their role in enhancing crop growth, improving soil biological activity, increasing nutrient availability, and reducing the need for external chemical inputs.

Vermiwash: Definition and Preparation

1 What is Vermiwash?

Vermiwash is a liquid biofertilizer obtained by passing water through a column containing active earthworms, vermicompost, and partially decomposed organic matter. The percolating liquid becomes enriched with earthworm excretions, mucus, enzymes, beneficial microorganisms, soluble nutrients, vitamins, and plant growth-promoting substances.

2 Preparation Method

A typical vermiwash unit consists of:

- A container or barrel with a drainage outlet
- Gravel or broken bricks at the bottom
- Sand layer
- Partially decomposed organic waste
- Vermicompost
- Earthworms (commonly *Eisenia fetida* or *Eudrilus eugeniae*)

Water is sprinkled regularly, and the collected brownish liquid is harvested periodically and diluted before application.

Composition of Vermiwash

Vermiwash contains a complex mixture of biologically active compounds.

Table 1. Major Components of Vermiwash

Component	Function
Nitrogen, phosphorus, potassium	Nutrient supply
Calcium, magnesium, micronutrients	Metabolic functions
Auxins and cytokinins	Growth promotion
Enzymes (protease, cellulase, amylase)	Organic matter transformation
Beneficial bacteria	Nutrient cycling
Vitamins and amino acids	Physiological stimulation

The exact composition varies with feedstock, earthworm species, moisture, and environmental conditions.

Cow-Based Formulations in Natural Farming

a) Jeevamrut

Jeevamrut is prepared by fermenting:

- Fresh cow dung
- Cow urine
- Jaggery
- Pulse flour (usually gram flour)

- Soil from the rhizosphere
- Water

Fermentation for 3–5 days produces a microbial-rich liquid used for soil application.

b) Beejamrut

Beejamrut is a seed treatment formulation made from cow dung, cow urine, lime, and water. It is used to protect seeds from pathogens and improve germination.

c) Panchagavya

Panchagavya is prepared from five cow-derived products:

- Cow dung
- Cow urine
- Milk
- Curd
- Ghee

Additional ingredients such as jaggery, banana, and coconut water are often included to enhance fermentation and microbial activity.

d) Cow Urine Extracts

Cow urine contains urea, minerals, phenolic compounds, and antimicrobial substances and is used as a foliar spray or component of fermented bio-inputs.

Mechanisms of Crop Growth Promotion

1 Nutrient Availability

Both vermiwash and cow-based formulations supply soluble nutrients and stimulate microbial processes that convert unavailable nutrients into plant-available forms.

2 Plant Growth Regulators

Auxins, gibberellins, and cytokinins present in these formulations promote:

- Cell division
- Root elongation
- Shoot growth
- Flower initiation
- Fruit development

3 Enhanced Root Development

Improved root architecture increases the soil volume explored by plants, leading to better water and nutrient uptake.

4 Rhizosphere Stimulation

Beneficial microorganisms introduced through these formulations colonize the rhizosphere and enhance nutrient cycling, phosphorus solubilization, nitrogen fixation, and disease suppression.

Effects on Crop Growth

Numerous studies have reported positive effects on various crops.

a) Seed Germination

Seed treatment with Beejamrut or diluted vermiwash often results in:

- Faster germination
- Higher germination percentage
- Improved seedling vigor

b) Vegetative Growth

Foliar application of vermiwash and Panchagavya has been associated with increased:

- Plant height
- Number of leaves
- Leaf area
- Chlorophyll content
- Biomass accumulation

c) Flowering and Yield

Enhanced physiological activity frequently leads to:

- Early flowering
- Increased number of flowers
- Better fruit set
- Higher yield
- Improved produce quality

These effects have been observed in vegetables, cereals, pulses, oilseeds, spices, and horticultural crops.

Soil Biological Activity

Soil biological activity is a key indicator of soil health and sustainability.

a) Microbial Population

Application of Jeevamrut and vermiwash increases populations of:

- Bacteria
- Fungi
- Actinomycetes
- Phosphate-solubilizing microorganisms
- Nitrogen-fixing microbes

b) Soil Enzyme Activity

Important soil enzymes stimulated by these formulations include:

- Dehydrogenase
- Urease
- Phosphatase
- β-glucosidase

Higher enzyme activity indicates greater microbial metabolism and nutrient transformation.

c) Soil Respiration

Increased microbial respiration reflects active decomposition and carbon cycling in the soil.

d) Organic Matter Dynamics

Regular application contributes to:

- Improved aggregate stability
- Enhanced humus formation
- Better soil structure
- Increased water infiltration and retention

Comparative Effects of Vermiwash and Cow-Based Formulations

Table 2. Comparative Characteristics

Parameter	Vermiwash	Cow-Based Formulations
Primary source	Earthworm system	Cow-derived products
Nutrient availability	High soluble fraction	Moderate
Microbial diversity	Moderate	High
Plant growth regulators	Abundant	Moderate to high

Parameter	Vermiwash	Cow-Based Formulations
Foliar suitability	Excellent	Good
Soil biological stimulation	Good	Excellent
Cost	Low	Very low

The two approaches are complementary rather than mutually exclusive.

Integration with Organic and Natural Farming

An integrated bio-input strategy may include:

- Beejamrut for seed treatment
- Jeevamrut for soil application
- Vermiwash for foliar nutrition
- Panchagavya during reproductive stages
- Vermicompost as basal organic manure

Such integration can create a biologically active production system with reduced dependence on synthetic inputs.

Environmental and Economic Benefits

Environmental Benefits

- Reduced chemical fertilizer use
- Lower risk of soil and water contamination
- Enhanced biodiversity
- Improved carbon sequestration
- Reduced ecological footprint

Economic Benefits

- Utilization of farm wastes
- Reduced input costs
- Increased profitability for smallholders
- Local production of bio-inputs
- Lower external dependency

These advantages make the technology particularly suitable for resource-poor farming communities.

Limitations and Challenges

Despite their potential, several challenges remain.

1) Variability in Composition: Nutrient and microbial content can vary widely depending on preparation methods and raw materials.

2) Lack of Standardization: Uniform protocols for preparation, storage, dilution, and application are often lacking.

3) Short Shelf Life: Fermented formulations may lose microbial viability during prolonged storage.

4) Scientific Validation: Although many field reports are positive, more rigorous multi-location and long-term studies are needed.

5) Quality Control: Contamination with undesirable microorganisms can occur if hygienic practices are not followed.

Future Research Directions

Future investigations should focus on:

- Standardization of formulations
- Microbial characterization using molecular tools
- Quantification of phytohormones and metabolites
- Dose optimization for different crops
- Long-term effects on soil carbon and microbial diversity
- Integration with precision and climate-smart agriculture
- Commercial formulation development with quality assurance standards

Conclusion

Vermiwash and cow-based formulations represent promising biological tools for sustainable crop production and soil health management. Vermiwash provides readily available nutrients, plant growth regulators, enzymes, and beneficial microorganisms that enhance crop growth and physiological performance. Cow-based formulations such as Jeevamrut, Beejamrut, and Panchagavya enrich the soil with diverse microbial populations and organic compounds that stimulate nutrient cycling, enzyme activity, and rhizosphere processes.

Their combined use can improve seed germination, vegetative growth, yield, soil microbial activity, and overall soil fertility while reducing dependence on synthetic agrochemicals. Although challenges related to standardization and scientific validation remain,

these formulations offer a practical, low-cost, and environmentally friendly approach for organic and natural farming systems. Continued research and quality assurance efforts will be essential for wider adoption and integration into sustainable agricultural production strategies.

References

1. Arancon NQ, Edwards CA, Bierman P, Welch C, Metzger JD. Influences of vermicomposts on field strawberries: Part 2. Effects on soil microbiological and chemical properties. *Bioresource Technology*. 2004;97:831–840.
2. Atiyeh RM, Lee S, Edwards CA, Arancon NQ, Metzger JD. The influence of humic acids derived from earthworm-processed organic wastes on plant growth. *Bioresource Technology*. 2002;84:7–14.
3. Kale RD. *Earthworms: Nature's Gift for Utilization of Organic Wastes*. Bangalore: Prism Books; 2004.
4. Palekar S. *The Philosophy of Spiritual Farming (Zero Budget Natural Farming)*. Amravati: Zero Budget Natural Farming Research, Development and Extension Movement; 2006.
5. Sreenivasa MN, Nagaraj M, Naik MK, Bhat SN. Beneficial traits of microbial isolates of organic liquid manures. *Proceedings of the First Scientific Conference of ISOFAR*; 2005.
6. Suthar S. Vermicomposting potential of *Perionyx sansibaricus* and *Perionyx excavatus* in different waste materials. *Bioresource Technology*. 2007;98:1231–1237.
7. Yadav BK, Lourdraj AC. Effect of organic manures and Panchagavya spray on growth and yield of rice. *Journal of Ecobiology*. 2006;19:393–397.
8. Xu HL. Effects of a microbial inoculant and organic fertilizers on the growth, photosynthesis and yield of sweet corn. *Journal of Crop Production*. 2000;3:183–214.

Volume: 06 Issue No: 09

AGRONOMIC INTERVENTIONS TO INCREASE THE PRODUCTIVITY IN SESAME

Article ID: AG-V06-I09-21

Bangaremma S. Wadeyar

All India Coordinated Research Project (AICRP) on Pearl Millet, Regional Agricultural Research Station (RARS), Vijayapura, UAS, Dharwad

Introduction

Sesame (*Sesamum indicum* L.) is one of the oldest cultivated oilseed crops belonging to the family Pedaliaceae and is popularly known as the "Queen of Oilseeds" because of its high-quality oil and nutritional value. The seeds contain about 46–64 per cent oil, 20–25 per cent protein and are rich in minerals and natural antioxidants. Sesame is widely cultivated in tropical and subtropical regions and is valued for its drought tolerance, short duration and adaptability to rainfed conditions. It is also an important export-oriented crop that provides income and livelihood opportunities to small and marginal farmers.

Globally, sesame is grown on about 12.8 million hectares with a production of 6.6 million tonnes. In India, it is cultivated on nearly 1.0 million hectares with a production of 0.84 million tonnes (Anon, 2024). However, its productivity remains low due to factors such as cultivation under rainfed conditions, poor nutrient management, moisture stress, weed infestation and use of low-yielding varieties. Agronomic interventions including improved varieties, optimum sowing time, proper spacing, balanced nutrient management, efficient water management and effective weed control play an important role in increasing sesame productivity. Therefore, understanding these interventions is essential for improving yield and ensuring sustainable sesame production.

RESEARCH FINDINGS

Land configuration and tillage practices

Teame et al. (2021) studied the effect of different land configuration methods on sesame in Ethiopia and reported that ridge and furrow method recorded significantly higher plant population (22.9 plants m^{-2}), capsules per plant (33.9) and grain yield (558 kg ha^{-1}) compared to

flat method which recorded 19.4 plants m^{-2}, 29.3 capsules per plant and grain yield of 400 kg ha^{-1}.The improved yield was attributed to better moisture conservation and root growth by adopting improved land configurations and tillage practices.

Sowing window and Planting geometry

Murthy et al. (2023) conducted a field experiment at Anakapalli, Andhra Pradesh to evaluate different sowing windows for sesame. The results indicated that sowing during the second fortnight of December recorded the higher number of branches $plant^{-1}$ (3.22), capsules $plant^{-1}$ (79.27) and seed yield (897 kg ha^{-1}), whereas sowing during the first fortnight of February recorded lower branches $plant^{-1}$ (1.71), capsules $plant^{-1}$ (47.60) and seed yield (409 kg ha^{-1}). The study suggested that sowing during December favours better growth and yield of sesame.

Monpara and Vaghasia (2016) conducted a study for three years at Junagadh, Gujarat to evaluate the influence of sowing windows and spacing on sesame productivity. Among spacing treatments, 30 × 10 cm spacing recorded the higher capsules $plant^{-1}$ (49.61), 1000-seed weight (2.91 g) and seed yield (1050 kg ha^{-1}), whereas 45 × 10 cm spacing recorded lower capsules $plant^{-1}$ (45.96) and seed yield (910 kg ha^{-1}). Further, interaction effect indicated that sowing on 15th February with 30 × 10 cm spacing produced the highest seed yield (1433 kg ha^{-1}).

Nutrient, Irrigation and Weed management

Lakhran et al. (2015) conducted a field experiment at Anand, Gujarat to evaluate the effect of nutrient management on yield attributes, yield and quality of sesame. The results revealed that application of 75% RDF + 5 t FYM ha^{-1} + biofertilizer recorded the higher number of capsules $plant^{-1}$ (54.86), seeds $capsule^{-1}$ (61.89), test weight (3.46 g), seed yield (1186 kg ha^{-1}), stalk yield (2440 kg ha^{-1}), oil content (48.48%) and oil yield (574.1 kg ha^{-1}). Whereas, application of 50% RDF + 5 t FYM ha^{-1} recorded lower seed yield (858 kg ha^{-1}), oil content (45.89%) and oil yield (393.4 kg ha^{-1}).

Mor (2025) conducted a field experiment at Anand Agricultural University, Jabugam, Gujarat during 2018–19 and 2019–20 to evaluate different irrigation schedules in sesame. The study revealed that irrigation at branching, flowering, capsule development and seed development stages recorded the highest capsules $plant^{-1}$ (72.56), seed yield (981 kg ha^{-1}), stover yield (1302 kg ha^{-1}), net returns (₹43,171 ha^{-1}) and benefit:cost ratio (2.79). The study concluded

that irrigation at all four critical growth stages is the most effective irrigation schedule for improving sesame productivity and profitability under summer conditions.

Mruthul (2014) conducted a field experiment at Raichur to evaluate weed management practices in sesame. Among the treatments alachlor 50 EC @ 0.75 kg a.i. ha-1 as PRE application + HW at 30 DAS + IC at 45 DAS and quizalofop ethyl 5 EC @ 40 g a.i. ha-1 as POE application at 20 DAS + IC at 45 DAS were found to be more effective in controlling weeds.

Conclusions

- Ridge and furrow land configuration helps to improve capsules plant^{-1} (33.9) and seed yield (558 kg ha^{-1}), over flat planting.
- Appropriate sowing window and spacing (15th February with 30 × 10 cm) maximized seed yield (1251 kg ha^{-1}) and 1000-seed weight (2.98 g), whereas wider spacing increased plant height (60.56 cm).
- Integrated nutrient management (75% RDF + 5 t FYM ha^{-1} + biofertilizer) enhanced seed yield (1186 kg ha^{-1}), oil content (48.48%) and oil yield (574.1 kg ha^{-1}), Compared to application of nutrients through chemical fertilisers alone.
- Irrigation at critical stages like branching, flowering, capsule development and seed development helped to improve the yield (981 kg ha^{-1}) and economics (₹43,171 ha^{-1} net returns and 2.79 B:C ratio).
- Weeds can be effectively managed by the pre-emergence application of alachlor 50 EC @ 0.75 kg a.i. ha^{-1} followed by one hand weeding at 30 DAS and intercultivation at 45 DAS or by the post-emergence application of quizalofop-ethyl 5 EC @ 40 g a.i. ha^{-1} at 20 DAS followed by intercultivation at 45 DAS resulting in a seed yield of about 480 kg ha^{-1}.

References:

Anonymous, 2024, Directorate of Oilseed Development, Annual report, Hyderabad.

Lakhran H, Sadhu A C and Kumawat S, 2015, Quality and yield potential of summer sesame (*Sesamum indicum* L.) as influenced by sowing time and nutrient management in middle Gujarat. *The Bioscan*, 10(3): 1409-1411.

Monpara B A and Vaghasia D R, 2016, Optimizing sowing time and row spacing for summer sesame growing in semi-arid environments of India. *International Journal of Current Research and Academic Review*, 4(1): 122-131.

Mor V B, 2025, Impact of dates of sowing and irrigation scheduling on growth and productivity at critical growth stages on sesame. *Indian Journal of Agronomy*. 70(2): 189–196.

Mruthul T, 2014, Chemical weed management in sesame (*Sesamum indicum* L.). M.Sc. (Agri.) Thesis, University of Agricultural Sciences, Raichur, Karnataka, India.

Murthy K V R, Nagarjuna D, Kumari M B G S, Sireesha A B M and Chitkala Devi T, 2023, Optimizing sowing window for sesame. *Ecology, Environment and Conservation*, 29(3): 1109-1114.

Teame G, Tsegay A and Weldearegay D, 2021, Effect of land configuration ways on soil moisture and sesame seed yield in Ethiopia. *Turkish Journal of Food and Agriculture Sciences*, 3(1): 1-6.

Volume: 06 Issue No: 09

WEED CONTROL METHODS: PHYSICAL AND CULTURAL METHODS

Article ID: AG-VO6-I09-22

[1]Dhayanithi P [2], R. Vinoth and [3]J. Gokulakrishnan

[1]B.Sc. (Hons) Agriculture**,** Institute of Agriculture (IOA), Tamil Nadu Agricultural University, Kumulur, Trichy, Tamil Nadu, India

[2]Teaching Assistant (PBG), Institute of Agriculture (IOA), Tamil Nadu Agricultural University, Kumulur, Trichy, Tamil Nadu, India

[3]Associate Professor (PBG), Institute of Agriculture (IOA), Tamil Nadu Agricultural University, Kumulur, Trichy, Tamil Nadu, India

*Corresponding Author : Dhayanithi P

Abstract:

Increasing concern about pesticide use and a steadily increasing physical and chemical to control the weed. This article reviews some of the major results achieved with non-chemical methods and have focused on optimizing the use mechanical or physical weeding methods against the weeds such as burning and flaming, hand weeding, hand hoeing, digging, mowing, cutting, dredging and chaining. The next method is cultural weed control methods such as field preparation, planting methods, varieties, planting density, fertilizer application, irrigation and drainage, cropping system, mulches and inter cultivation. So far, non-chemical methods have had little uptake in conventional farming, but national and EU-based legislative initiatives may change the situation radically soon. Several European countries have launched pesticide action plans and the EU a new directive for the implementation of integrated pest management (IPM); all aiming for minimizing the reliance on herbicides. This is expected to accentuate the need for nonchemical methods.

Key words: Physical or Mechanical Methods, Cultural Methods

Introduction

Plants are differentiated into crops which meet the needs of man and weeds which compete with crops. The first person to use the word weed in the present-day meaning was *Jethro Tull (1674-1741A.D.)* Subsequently, several definitions were proposed.

- A weed is a plant growing where it is not wanted
- Weed is an unwanted plant
- A plant out of place
- A plant that is extremely noxious, useless, unwanted or poisonous
- Any plant or vegetation, excluding fungi, interfering human activities, it is not called as weed

  From the definitions, if plant is not interfering with human activities, it is not called as weed. *(Reddy & Reddy 4th edition, 2010)*

In recent years, physical and cultural methods are gradually moved into European agricultural sector. *Become management options that may expand further in the future. The changes of focus from herbicides to more sustainable solutions have been driven fects of herbicides and the need for regulations. Also, an increasing conversion to organic farming, favourably subsidised by some European countries, has plaid as significant role. Research projects have been granted to develop nonchemical weed management in horticultural and agricultural crops.* considerable scientific publications have been produced and a European network (*WWW.ewrs.org/pwc*) discussing and dissemination information about non-chemical weed management was established in 1994 and is still operating. MELANDER et al., 2005

The increasing emphasis on sustainable agriculture, environment conversion, and food security has renewed interest in integrating physical and cultural weed control methods into modern farming systems. This approaches not only reduce dependence on herbicide but also contribute to improve soil health, biodiversity conversion and long-term agricultural sustainability. Understanding the principles, advantages, limitations, and practical applications of physical and cultural weed control methods is therefore essential for developing effective integrated weed management strategies. This article provides a comprehensive overview of the major physical and cultural methods of weed control, their mechanism of action, benefits, limitations and their role in promoting sustainable and economically viable crop production.

PRINCIPLES

A) Prevention

B) Eradication

C) Control

D) Management

A) PREVENTION

It encompasses all measures taken to prevent the introduction and/or establishment and spread of weeds. Such areas may be local, regional

Or national in size. No weeds control programme is successful if adequate prevention measures are not taken to reduce weed infestation. It is a long-term planning so that the weeds could be controller or managed more effectively and economically than is possible where these are allowed to disperse freely.

Following preventive control measures are suggested for adoption wherever possible & practicable.

1. Avoid using crop that are infested with weed seed for sowing.
2. Avoid feeding screening and other material containing weed seeds to the farm animals.
3. Avoid adding weeds to the manure pits.
4. Clean the farm machinery thoroughly before moving it from one field to another field. This is particularly for seed drills.
5. Avoid the use of gravel sand and soil from weed infested.
6. Inspect nursery for weed the presence of weed seedlings, tubers, rhizomes, etc.
7. Keeping irrigation channels, fenceline and un-cropped areas clean.
8. Use vigilance. Inspect your farm frequently for any strange looking weed seedling. Destroy such patches of a new weed by digging and burrowing the weed along with its roots. Sterilise the spot with suitable chemical.
9. Quarantine regulations are available in all countries to deny the entry of weed seeds and other propagules into a country to deny the entry of weed seeds and other propagules into a country through airports and shipyards.

B) ERADICATION

- Complete elimination or removal of all living weeds/wild pants/plants including their seeds and vegetative propagules from certain area.

- Eradication of newly introduced weed is the best way to prevent establishment.
- Eradication can be achieved by various methods, including manual removal, mechanical methods like mulching, using herbicides & promoting plant growth to out compete them.
- Justified only foe the elimination of serious weeds in a limited area (perennial weeds such as ***Cyperus rotundus, cynodont dactylon*** *)*

C)CONTROL

It encompasses those processes whereby weed infestations are reduced but not necessarily eliminate. It is a matter degree ranging from poor to excellent. In control methods, the crop makes a normal yield. In general, the degree of weed control obtained is dependent on the characters of weeds involved and the effectiveness of the control method used.

D)WEED MANAGEMENT

Weed control aims at only putting down the weeds present by some kind of physical or chemical means while weed management is a system approach whereby whole land use planning is done in advance to minimize the very invasion of weeds in aggressive forms and give crop plants a strongly competitive advantage over the weeds involved and the effectiveness of the control method used.

Weed control methods are grouped into cultural, physical, biological and chemical methods. Every method of weed control has its own advantages and disadvantages. No single method is effective and economic control than a single method.

MECHANICAL WEED CONTROL

Mechanical or physical methods of weed control are being employed ever since man began to grow crops. The mechanical method includes tillage, hoeing, hand weeding, digging, cheering, sickling, burning, flooding, mulching etc.

1. **Tillage:**

   Tillage is a core mechanical weed control method that uses physical soil disturbance such a ploughing, disking, and cultivating – to sever, uproot, bury, or dry out weeds.



2.Hoeing

Hoeing is defined as a mechanical weed control method that involves the use of tools like hand hoes or powered equipment to manage weeds effectively and enhance crop yield, particularly in the early growth stages of crops.



3. Hand Weeding

it is done by physical removal or pulling out of weeds by hand or removal by implements called khurpi, which resembles sickle. It is probably the oldest method of controlling weeds, and it is still a practical and efficient method of eliminating weeds in cropped and non-cropped lands.it is very effective against annual, biennial and upper portions of perennials.



4.Digging

Digging is very useful in the case of perennial weeds to remove the underground propagation parts of weeds from the deeper layer of the soil.



5.sickling and mowing

Sickling is also done by hand with the help of sickle to remove the top growth of weeds to prevent seed production and to starve the underground parts. It is popular in slopy areas where only the tall weed growth is sickle leaving the roots system to hold the soil in place to prevent soil erosion. **Mowing** is a machine operated practice mostly done on roadside and in lawns.



Sickling



Mowing

6.Burning

Burning or fire is often an economical and practical means of controlling weeds. it is used to (a) dispose of vegetation (b) destroy dry tops of weeds that have matured (c) kill green weed growth in situations where cultivations and other common methods are impracticable.



8.Flooding

Flooding is successful against weed species sensitive to longer periods of submergence in water. Flooding kills plants by reducing oxygen availability for plant growth. The success of flooding depends upon complete submergence of weeds for longer periods.



Merits of Mechanical Methods

1) Oldest, effective and economical method
2) Large area can be covered in shorter time
3) Safe method for environment
4) Does not involve any skill
5) Weeding is possible in between plants
6) Deep rooted weeds can be controlled effectively

Demerits of Mechanical Method

1) Labour consuming
2) Possibility of damaging crop
3) Requires ideal and optimum specific condition.

CULTURAL WEED CONTROL

Cultural weed control is a non-chemical crop management method that uses regular farming practices like crop rotation, dense planting, and good selection to help crop outgrow weeds. It creates field conditions that Favor the main crop and stop weeds from growing well. Several cultural practices like tillage, planting, fertilizer application, irrigation ect., are employed for creating favourable condition for the crop. These practices if used properly, help properly, help in controlling weeds. Cultural methods alone cannot control weeds but help in reducing weed population. They should, therefore, be used in combination with other methods. In cultural methods, tillage, fertilizer application, and irrigation are important. In addition, aspects like selection of variety, time of sowing, cropping system, cleanliness of the farm etc., are also useful in controlling weeds.

1) Field preparation

To maintain the field as weed free.

Weeds are should not allowed to flowering stage.



This can prevent the weed seed population.

2) Summer tillage

summer tillage or off-season tillage is one of the effective cultural methods to check the growth of perennial weeds.

Initial tillage before cropping should encourage the clod formation. These clods, which have the weed propagules, upon drying desiccate the same. Subsequent tillage operations should break the clods into small units to further expose the shrivelled weeds to the hot sun.



3) Optimum plant population to be maintained

Lack of plant population enhance the weed population.

This can be managed by selection of proper seed materials, right method of sowing, adequate seed rate and protection of seed from soil borne pest and disease.

4) Crop rotation

The possibilities of some group of weed species occurring is higher if the same crop is grown year after year. crop rotation can be check at least reduce the weed infestation.



5) Growing of intercrops

Intercrop can be suppressed the weeds better than sole cropping and thus provides an opportunity to utilize crop themselves as tool of weed management.

Many short duration pulses viz., green gram and soybean effectively smother weeds without causing reduction in the yield of main crop.



6) Mulching

Mulch is a physical covering material to protect the soil surface. Mulching has smothering effect on weed control by excluding light from the photosynthetic portion of plant and thus inhibiting the top growth.



7) Solarisation

By use of solar energy to desiccate the weeds.

The soil temperature is further raised by 5-10 degrees C by covering a pre-soaked fallow field within the transparent plastic sheet. The plastic sheet checks the long wave back radiation from the soil and prevent loss of energy by hindering moisture evaporation.



8) Bind tillage

The tillage of the soil after sowing of crop but before the crop plants emerge is known as blind tillage. It can be minimising the weed intensity.



9) Crop management practices

Good crop management practices the play an important role in weed control are

a) Vigorous and fast-growing crop varieties are better competitors with weeds.
b) Proper placement of fertilizers.
c) Better irrigation practices.
d) Proper crop rotation.
e) Optimum plant population.

Merits of Cultural Method

a) Low of cost for weed control
b) Easy to adopt
c) No residual problem
d) Technical skill is not involved
e) No damage to crops
f) Effective weed control
g) Crop weed ecosystem is maintained

Demerits of Cultural Method

a) Immediate and quick weed control is not possible
b) Weeds are kept under suppressed condition
c) Perennial and problematic weeds cannot be controlled
d) Practical difficulty in adoption

Conclusion

Weed control is an essential component of successful crop production because weeds compete with crops for water, nutrients, light and space, there by reducing crop growth and yield. Physical methods such as hand weeding, hoeing, tillage and mowing are useful for directly removing weeds and are environmentally safer, while cultural methods such as crop rotation, proper spacing, timely sowing, optimum plant population, competitive crop varieties, and proper nutrients and water management reduce the growth and establishment of weeds. Although these methods may require more labour and proper planning, their regular and timely adoption can significantly reduce weed competition and improve crop growth and yield. Integrating physical and cultural methods with other sustainable approach to reduce weed problems, maintaining soil health, and promoting safe and productive agriculture.

Volume: 06 Issue No: 09

CHROMATOGRAPHY: UNVEILING THE HIDDEN WORLD OF MOLECULES

Article ID: AG-V06-I09-23

Pearl Saharan

Department of Microbiology

Guru Jambheshwar University of Science and Technology, Hisar, Haryana 125 001, India

Abstract

Chromatography is one of the most powerful separation techniques used in modern Sciences. It allows scientists to separate, identify, and analyse the different components present in a complex mixture by exploiting their different interactions with a stationary phase and a mobile phase. From separating pigments in a plant extract to analysing proteins, pharmaceuticals, metabolites, and environmental contaminants, chromatography has become an essential tool in life sciences. Different forms of chromatography, including paper chromatography, thin-layer chromatography, column chromatography, gas chromatography, high performance liquid chromatography, ion exchange chromatography, size exclusion chromatography, and affinity chromatography, provide solutions for analysing molecules with very different properties. In microbiology and biotechnology, chromatography contributes to protein purification, drug development, metabolite analysis, quality control, and proteomics. With advances in automation, high resolution separation, multidimensional chromatography, and coupling with mass spectrometry, chromatography continues to reveal molecular information that would otherwise remain hidden. Chromatography is not simply a lab separation method but a bridge between complex biological mixtures and meaningful molecular information.

Key words: Biotechnology; Chromatography; HPLC; Microbiology; Molecules; Protein purification; Separation

Introduction

A biological sample may look simple to the human eye, but at the molecular level it can contain thousands of different substances. A drop of blood, a plant extract, a microbial culture, or

a pharmaceutical formulation may contain proteins, carbohydrates, lipids, pigments, metabolites, nucleic acids, and other compounds. Studying these molecules individually is difficult when they are present together. Chromatography provides a solution by separating the components of a mixture according to their different chemical and/or physical interactions [1]. According to the International Union of Pure and Applied Chemistry, chromatography is a physical separation method in which components are distributed between two phases: a stationary phase and a mobile phase. The stationary phase remains fixed, while the mobile phase moves through or along it. Different molecules interact differently with the phases, causing them to travel at different rates and ultimately become separated.

The basic idea behind chromatography is remarkably simple. Molecules that behave differently can be made to move differently. The principle has developed into a sophisticated collection of techniques that are now central to analytical chemistry, microbiology, biotechnology, medicine, food science, environmental science, and pharmaceutical research [2].

Principle Behind Chromatography

Chromatographic separation depends mainly on the distribution of molecules between the stationary and mobile phases. The stationary phase may be a solid, a gel, or a liquid immobilised on a solid support, whereas the mobile phase may be a liquid, gas, or, in specialised systems, a supercritical fluid. When a mixture is introduced into a chromatographic system, its components repeatedly interact with the two phases. A molecule that has a stronger interaction with the stationary phase tends to move more slowly, whereas a molecule that prefers the mobile phase moves more rapidly. The components gradually become separated [3].

The process can be imagined as a molecular race in which every molecule has a different preference for the road it is travelling on. Some molecules spend more time attached to the stationary phase, while others travel more freely with the mobile phase. Their different travelling speeds create separation. The exact mechanism depends on the type of chromatography. Separation may occur through adsorption, partition, differences in molecular size, charge, or highly specific biological interactions.

Types of Chromatography

Chromatography has evolved into many forms, each designed for particular types of molecules and analytical problems [4].

Paper and Thin Layer Chromatography

Paper chromatography and thin layer chromatography (TLC) are simple forms of planar chromatography. The stationary phase is present on a flat surface. TLC commonly uses a thin layer of solid particles spread over a support, while paper chromatography uses paper as the stationary medium. The techniques are particularly useful for teaching lab and preliminary analysis. Plant pigments, amino acids, dyes, drugs, and other small molecules can be separated and visualised as distinct spots. TLC is also widely used to monitor chemical reactions and compare samples.

Column Chromatography

The stationary phase is contained inside a tube or column, through which the mobile phase passes. Components of a mixture move through the column at different rates and are collected in separate fractions. Column chromatography is especially important in biotechnology because it can be used to purify biological molecules. Different forms of column chromatography can be selected depending on the properties of the target molecule.

High Performance Liquid Chromatography (HPLC)

HPLC is one of the most important modern chromatographic techniques. It is a form of liquid chromatography that uses very small stationary phase particles and relatively high pressure to achieve efficient separation. HPLC is widely used for the separation, identification, and quantification of complex biological and pharmaceutical compounds. It can analyse molecules present at relatively low conc and is extremely valuable in pharmaceutical research and quality control. Different HPLC modes include reversed phase, ion exchange, size exclusion, and affinity chromatography.

Gas Chromatography (GC)

It uses a gas as its mobile phase and is particularly useful for compounds which can be vaporised without decomposing. It is commonly applied in areas such as environmental analysis, food chemistry, forensic science, and the analysis of volatile organic compounds.

Ion Exchange Chromatography

This separates molecules according to their electrical charge. Charged molecules interact with oppositely charged groups present on the stationary phase. By changing conditions such as pH or ionic strength, molecules can subsequently be released from the column. It is highly useful

for the separation and purification of proteins, peptides, amino acids, and other charged biological molecules.

Size Exclusion Chromatography

Separates molecules according to their mol size. The stationary phase contains pores through which smaller molecules can enter, while larger molecules are excluded from some of the spaces and therefore travel through the column differently. This is useful for analysing proteins and other macromolecules and can also provide information about molecular size distributions.

Affinity Chromatography

It is one of the most selective forms of chromatography because it relies on specific biological interactions between molecules. A target molecule binds to a complementary ligand attached to the stationary phase, while unrelated molecules pass through. Affinity chromatography has become particularly important in proteomics and protein purification. It can be used for selective enrichment of proteins and biomarkers and for studying protein interactions and post translational modifications.

Chromatography in Microbiology and Biotechnology

Chromatography is much more than an analytical technique. It is an important part of understanding and manipulating biological systems. Microbes produce a wide variety of metabolites, enzymes, pigments, antibiotics, and other bioactive compounds. It can help separate these compounds from complex culture media and identify the molecules produced by microbes.

Protein purification is another major application. Recombinant proteins produced using bacterial, yeast, or mammalian expression systems often require several purification steps. Affinity, ion exchange, and size exclusion chromatography can help obtain proteins with high purity. Chromatography is also important in pharmaceutical biotechnology. HPLC is used to evaluate the purity, potency, and stability of biopharmaceutical products such as recombinant proteins and monoclonal antibodies. In metabolomics and proteomics, chromatography is frequently combined with highly sensitive detection systems to separate complex mixtures before molecular identification. It allows researchers to investigate biological changes which cannot be understood by looking at the whole mixture at once [5].

From Coloured Spots to Molecular Fingerprints

One of the most fascinating aspects of chromatography is how an apparently invisible molecular difference can become a visible pattern or measurable signal. In a simple TLC experiment, a mixture may produce several separated spots on a plate. In HPLC, these separated components appear as peaks in a chromatogram. Each peak represents a component detected as it leaves the column, and its position and intensity can provide valuable information about the sample [6].

The chromatogram can be considered a kind of mol fingerprint. Scientists can compare chromatographic patterns between samples to detect similarities, differences, impurities, and/or changes in biological composition. It makes chromatography particularly useful when the original sample is too complex to interpret directly.

Chromatography and Modern Life Sciences

The importance of chromatography continues to increase as biological research becomes more molecular and data driven. Modern research often deals with extremely complex mixtures containing thousands of molecular components. Advanced chromatographic systems provide greater separation efficiency and can be combined with other analytical technologies. Chromatography coupled with mass spectrometry, allows researchers to separate components before determining their mol characteristics [7].

Two dimensional and multidimensional separation approaches can provide even greater resolving power for highly complex samples. These developments are particularly relevant to proteomics, metabolomics, pharmaceutical analysis, and biomarker discovery. Recent research in liquid chromatography continues to address fundamental questions concerning retention, mobile phase vol, and measurement practices, demonstrating that even a mature technique such as chromatography continues to evolve.

Challenges and Future Prospects

Despite its enormous usefulness, chromatography also presents several challenges. Selecting the appropriate stationary phase, mobile phase, flow rate, temp, pressure, and detection method strongly influence separation quality. Complex biological samples may also produce overlapping peaks or matrix interference, making interpretation difficult. Advanced chromatographic instruments can also be expensive and require skilled operation. Sample

preparation, solvent consumption, column maintenance, and method optimisation may increase the time and cost of analysis.

The future of chromatography is likely to focus on faster, more sensitive, automated, and environmentally sustainable separation systems. Improved stationary phases, miniaturised systems, multidimensional chromatography, and integration with mass spectrometry and computational analysis are expected to expand its applications. For biotechnology and microbiology, chromatography will remain important as research moves toward complex biological systems, personalised medicine, biomarker discovery, advanced therapeutics, and large scale bioprocessing.

Conclusion

Chromatography has transformed the way scientists study complex mixtures. From a simple separation of coloured plant pigments to the purification and analysis of sophisticated biological molecules, it provides a powerful way to uncover components that cannot be distinguished by simple observation. Its strength lies in a fundamental principle: molecules interact differently with different environments, and those differences can be used to separate them. Modern techniques such as HPLC, affinity chromatography, ion exchange chromatography, size exclusion chromatography, and multidimensional separation have expanded this principle into an essential technology for life sciences.

For microbiologists and biotechnologists, chromatography provides a pathway from a complex sample to purified molecules and meaningful biological information. As analytical technologies continue to become more sensitive and precise, chromatography will remain an important tool for unveiling the hidden world of molecules.

References

1. International Union of Pure and Applied Chemistry (IUPAC). (2025). Chromatography. IUPAC Compendium of Chemical Terminology, Gold Book. DOI: 10.1351/goldbook.C01075.
2. International Union of Pure and Applied Chemistry (IUPAC). (2025). Liquid chromatography. IUPAC Compendium of Chemical Terminology, Gold Book. DOI: 10.1351/goldbook.L03578.

3. International Union of Pure and Applied Chemistry (IUPAC). (2025). Stationary phase. IUPAC Compendium of Chemical Terminology, Gold Book. DOI: 10.1351/goldbook.S05949.
4. International Union of Pure and Applied Chemistry (IUPAC). (2025). Mobile phase. IUPAC Compendium of Chemical Terminology, Gold Book. DOI: 10.1351/goldbook.M03952.
5. Chamrád, I., Simerský, R., Lenobel, R., & Novák, O. (2024). Exploring affinity chromatography in proteomics: a comprehensive review. Analytica Chimica Acta, 1306, 342513.
6. Mahdi, G., Alamdary, A., Kaghazian, H., Ahmadi, N., Mardani, R., & Gholami, A. (2025). Biopharmaceutical analysis by HPLC: Practices and challenges. Chonnam Medical Journal, 61(1), 19.
7. Mollen, J., Desmet, G., & Cabooter, D. (2026). Revisiting the definition and measurement of total accessible and hold-up volumes in liquid chromatography: Current understanding and advances. Journal of Chromatography A, 466849.

Volume: 06 Issue No: 09

COW URINE: A VALUABLE FARM RESOURCE FOR SUSTAINABLE AGRICULTURE

Article ID: AG-VO6-I09-24

***Selva Rani, A[1] and Bommayasamy, N.[2]**

[1]Assistant Professor, Agricultural Research Station, Kovilpatti, Thoothukudi, Tamil Nadu

[2]Senior Scientist & Head, ICAR-KVK, CCARI, Ela, Old Goa, North Goa, Goa, India

*Corresponding Author: Selva Rani, A

Abstract

Cow urine is an important livestock-derived resource with potential applications in sustainable agriculture.It contains nitrogen, potassium, minerals and various organic compounds that can contribute to nutrient recycling. Its utilization helps convert livestock waste into useful farm inputs and supports circular farming systems. Cow urine is traditionally used in organic and natural farming practices as a component of several agricultural formulations. It is an important ingredient in preparations such as Panchagavya and Dasagavya. These formulations are used for crop growth promotion, nutrient management and plant protection. Cow urine-based botanical extracts have also been explored for managing insect pests and certain plant pathogens. Research has reported plant-growth-promoting and antimicrobial activities under specific experimental conditions.

Its effectiveness depends on crop, concentration, preparation method, application timing and environmental conditions. Cow urine can be used as a supplementary input rather than a complete replacement for fertilizers or pesticides. Integration with crop residues, livestock manure and biofertilizers can improve farm-level nutrient recycling. It has particular relevance to small and marginal farmers practicing integrated farming systems. Proper collection, filtration, storage, dilution and application are essential for safe and effective utilization. Standardization and field-level validation are needed to establish crop-specific recommendations and economic benefits. Thus, scientifically validated utilization of cow urine can contribute to low-cost, resource-efficient and sustainable agricultural production.

Introduction

Agriculture is increasingly moving towards production systems that are economically viable, environmentally safe and resource-efficient. Rising input costs, declining soil health, excessive dependence on external inputs and concerns about environmental pollution have encouraged farmers to make better use of resources available within the farm. In this context, livestock and crop enterprises can complement each other through efficient recycling of farm wastes. Among the livestock-derived resources, cow urine is an important but often underutilized farm resource. Traditionally known as *gomutra*, cow urine has been used in Indian farming systems for generations as an ingredient in organic formulations, plant extracts and natural farming preparations. Modern agricultural research has also investigated its potential as a nutrient source, plant-growth promoter, biopesticide and component of integrated crop management. Cow urine should not, however, be viewed as a "miracle input" or as a universal replacement for chemical fertilizers and pesticides. Its agricultural value depends on the crop, concentration, preparation method, timing, environmental conditions and purpose of application. Scientific validation and proper standardization are therefore important for its wider adoption.

What is present in cow urine?

Cow urine is predominantly water, but it also contains various dissolved nutrients and organic compounds. Published literature describes nitrogen, potassium and other mineral elements, together with compounds such as enzymes and salts. Its composition can vary considerably depending on animal breed, age, diet, physiological condition, water intake and collection method. The presence of nitrogen-containing compounds makes cow urine potentially useful as a supplementary nutrient source. Potassium and other minerals can also contribute to nutrient recycling within integrated crop-livestock systems. It is important to recognize that the nutrient concentration of cow urine is not fixed. Therefore, it should not automatically be treated as an equivalent substitute for a quantified dose of urea or other fertilizer. Laboratory analysis is necessary when precise nutrient replacement is intended.

Cow Urine and Soil Fertility

Soil fertility depends on the continuous supply and cycling of essential plant nutrients. In mixed crop-livestock farming, nutrients removed from the field through crop production can partly be returned through animal manure and urine. Cow urine can therefore contribute to nutrient recycling at the farm level. Instead of allowing urine to be lost from cattle sheds, farmers

can collect it hygienically and utilize it as an ingredient in suitable agricultural preparations. The greatest value of cow urine in this context is not simply the nutrients contained in the liquid, but its role in creating a closed nutrient cycle:

Crop residues → livestock feed → livestock → urine and dung → farm-made inputs → soil → crop → livestock.

Such recycling can reduce wastage of nutrients and improve the efficiency of available farm resources. However, cow urine alone cannot supply all nutrients required by a high-yielding crop. Phosphorus, micronutrients and other nutrient requirements must be considered through a balanced soil-fertility programme.

Cow Urine as a Plant Growth Promoter

One of the important areas of research is the use of cow urine as a supplementary input for crop growth. Foliar application has been studied because nutrients and other soluble compounds can be brought into contact with plant foliage. An ICAR-published study on wheat found that combining recommended fertilizer management with foliar application of cow urine enhanced growth and yield parameters compared with fertilizer management without the cow-urine treatment. Similarly, field experiments in rice found positive responses to cow-urine foliar sprays. In one study, four foliar sprays of cow urine were associated with increases in grain yield, with the reported increase reaching about 10% at the 100% concentration compared with the control under the experimental conditions.These results indicate that cow urine may have a supplementary role in crop nutrition, particularly when integrated with recommended nutrient management.

Cow Urine in Seed Treatment

Seed treatment is one of the most important steps in crop production because healthy and vigorous seedling establishment determines the initial crop stand. Cow-based preparations have traditionally been used for seed treatment in organic and natural farming systems. The objective is generally to improve seedling establishment and protect seed from certain harmful microorganisms. However, seed treatment should be carried out according to crop-specific and scientifically validated recommendations. Concentrated or improperly prepared materials may adversely affect germination.

For this reason, farmers should:

1. Use clean and healthy seed.

2. Use properly prepared and filtered formulations.
3. Follow crop-specific recommended concentrations.
4. Test the treatment on a small seed quantity before large-scale application.
5. Combine biological approaches with recommended seed-treatment practices whenever necessary.

Cow Urine as a Foliar Spray

Foliar application is another important method of utilizing cow urine. Since cow urine contains soluble compounds, appropriately diluted preparations can be sprayed on the foliage. The response depends on:

- Crop species
- Crop growth stage
- Concentration
- Weather conditions
- Spray volume
- Frequency of application
- Nutrient status of the crop
- Method of preparation

Farmers should avoid spraying highly concentrated preparations during hot and dry weather, particularly on tender foliage, because excessive concentration may cause leaf injury. A small-area test is advisable before applying any unfamiliar preparation throughout the field.

Cow Urine for Pest Management

Perhaps the most popular agricultural use of cow urine is in natural pest-management preparations. Cow urine may be used alone or, more commonly, in combination with plant materials such as neem, chilli, garlic and other botanicals. Research has examined its potential against several groups of agricultural pests. A review published in the *Indian Journal of Entomology* reported that cow urine combined with plant extracts or decoctions was generally more effective than cow urine alone against several groups of pests, including defoliators, sap-sucking insects, fruit flies and borers. Research on whitefly management has also reported the use of cattle urine and botanical extracts against whiteflies and other pests.

Why combine cow urine with botanicals?

Botanical plants contain biologically active compounds. Cow urine can act as a carrier or

extraction medium in some traditional preparations, while the plant material supplies compounds with insecticidal or repellent properties.

Cow Urine and Disease Management

Cow urine has also attracted attention because of its potential antimicrobial properties. Laboratory and experimental studies have investigated cow urine against fungal and bacterial organisms. However, laboratory inhibition does not necessarily mean reliable disease control under field conditions. Therefore, cow urine-based preparations should be considered as supportive components of integrated disease management, along with:

- Resistant varieties
- Healthy seed
- Crop rotation
- Proper plant spacing
- Field sanitation
- Balanced nutrition
- Biological control
- Proper irrigation management
- Recommended fungicides/bactericides where necessary

Panchagavya: A Popular Cow-Based Agricultural Preparation

One of the best-known agricultural preparations containing cow urine is Panchagavya.

According to the TNAU Agritech Portal, Panchagavya is prepared from cow dung, cow urine, milk, curd and ghee, with some farmer practices incorporating additional ingredients such as jaggery, banana and tender coconut water.TNAU describes Panchagavya as an organic preparation with potential growth-promoting effects and provides preparation and application information for agricultural use.

Panchagavya is widely used in organic and natural farming systems for:

- Seed treatment
- Nursery management
- Foliar application
- Crop growth promotion
- Improving crop vigour
- Supporting integrated crop management

Conclusion

Cow urine is a valuable livestock-derived resource with promising applications in sustainable agriculture. Its potential extends from nutrient recycling and crop growth promotion to botanical pest-management preparations, Panchagavya production and integrated crop-livestock farming. Scientific studies have reported positive responses in crops such as rice and wheat under particular experimental conditions. Research has also demonstrated potential for use with botanicals in pest management, although its performance is variable and generally should not be assumed to equal that of synthetic pesticides. The greatest opportunity lies in combining traditional knowledge with modern scientific validation. Standardization of concentration, preparation, application timing and crop-specific recommendations will be essential for wider adoption.

For sustainable agriculture, the message is simple:

"Do not treat livestock waste as waste—convert it into a resource through scientific nutrient recycling."

The recent news circulating about a ₹10/litre cow-urine procurement initiative in Uttar Pradesh. Recent reports from Bulandshahr have documented cow-urine collection and purchase from farmers/women's groups, with reported prices of ₹10–20/litre depending on the collection system. Cow urine, when properly collected, prepared and judiciously used, can contribute to low-cost, resource-efficient and environmentally conscious farming, particularly when integrated with livestock, crop residues, organic manures, biofertilizers, botanical extracts and other components of integrated farming systems.

References

1. Pradhan, S.S., Verma, S., Kumari, S. and Singh, Y. (2018). Bio-efficacy of cow urine on crop production: A review. *International Journal of Chemical Studies*, 6(3): 298–301.
2. Sadhukhan, R., Bohra, J.S., Singh, R.K., Hasanain, M., Sen, S. and Mondal, B.P. Integrated nutrient management with cow urine foliar application in wheat. *The Indian Journal of Agricultural Sciences*, 90(3).
3. Gahukar, R.T. (2020). Advances in cow urine mixture application for crop pest management. *Indian Journal of Entomology*, 82(4): 653–657.
4. Sadhukhan, R., Bohra, J.S. and Sen, S. Growth and yield response of rice to graded doses of nutrients and foliar spray of cow urine. *Indian Journal of Agronomy*, 64(1).

5. TNAU Agritech Portal. Organic Farming – Panchagavya and preparation of organic inputs.
6. de Jesus, D., Bianchi, V., Carbonera, R. and Gonzalez da Silva, J.A. Cow urine as a biopesticide and biorepellent: A systematic literature review.

Volume: 06 Issue No: 09

EL NINO AND APPROPRIATE FARM MANAGEMENT: BUILDING CLIMATE-RESILIENT AGRICULTURE THROUGH PPFM

Article ID: AG-VO6-I09-25

Dr. S.R.Padma

Assistant Professor (Agrl.Extension), Tamil Nadu Agricultural University

Coimbatore, Tamil Nadu, India

Introduction

Agriculture is closely linked with weather and climate. Changes in rainfall, temperature, humidity and the occurrence of extreme weather events directly influence crop growth, productivity and farm income. Among the major climate phenomena that can affect agricultural production, El Nino is particularly important because it can influence rainfall patterns and temperature conditions over large regions. El Nino is a natural climate phenomenon associated with the periodic warming of sea surface temperatures in the central and eastern tropical Pacific Ocean. Its effects are not uniform everywhere, but it can alter normal rainfall patterns and increase the possibility of dry spells, delayed rainfall and higher temperatures in some agricultural regions. For farmers, such changes can create uncertainty in sowing, irrigation, crop growth, pest and disease incidence and harvesting.

However, El Nino does not necessarily mean crop failure. The impact of El Nino can be reduced through timely planning, appropriate crop selection, efficient water management and scientific farm management**.** Precision and appropriate farm management approaches such as PPFM can help farmers make decisions according to the actual field situation rather than following a uniform practice.

El Nino – A Challenge and an Opportunity for Better Farm Planning

The major agricultural challenge during an El Niño-influenced season is uncertainty. Farmers may experience delayed onset of rainfall, prolonged dry spells, high daytime temperatures and increased water requirements. These conditions may affect seed germination, crop establishment, flowering, fruit setting and grain or fruit development.

Instead of waiting for the problem to occur, farmers can adopt a **"**prepare before the stress" approach. Farm planning should begin before sowing by considering rainfall forecasts, available irrigation water, soil type, previous crop, expected duration of the crop and availability of inputs.

The basic principle should be:

"Right crop + right variety + right time + right input + right amount of water = climate-resilient farming."

Appropriate Crop and Variety Selection

Crop selection is one of the first and most important decisions under uncertain weather conditions. When rainfall is expected to be irregular, farmers should consider crops and varieties that have comparatively shorter duration, better drought tolerance and suitability to the local agro-climatic conditions. Where appropriate, short-duration crops can help farmers complete the crop within the available moisture period. Drought-tolerant varieties recommended by agricultural universities and research institutions should be preferred whenever they are suitable for the particular region.

Farmers should also avoid concentrating the entire farm on a single crop when weather uncertainty is high. Crop diversification can reduce risk. Combining cereals, pulses, oilseeds, fodder crops, horticultural crops or suitable intercrops can provide better resilience and improve income stability.

Water Management – The First Line of Defence

During an El Nino situation, every drop of water becomes valuable. Efficient water management should therefore receive the highest priority. Drip and sprinkler irrigation can reduce water wastage and deliver water closer to the crop root zone. Irrigation should be scheduled according to crop requirement, soil moisture and crop growth stage rather than following a fixed calendar.

Critical stages such as establishment, flowering and fruit/grain development require particular attention. Unnecessary irrigation should be avoided, while moisture stress at critical stages should be prevented. Rainwater harvesting structures, farm ponds, field bunds and other moisture-conservation measures can help store rainfall and improve water availability during dry periods.

Protecting Soil Moisture

Healthy soil acts as a natural water reservoir. Increasing the organic matter content of soil improves its capacity to retain moisture and supports better root growth.

Farmers can improve soil moisture retention and soil health by incorporating **farmyard manure, compost, vermicompost, green manures, crop residues and other suitable organic amendments** into the soil. **Mulching with crop residues or other suitable materials** can further reduce evaporation, moderate soil temperature and conserve moisture around the crop root zone. These practices improve soil structure, enhance water-holding capacity and help crops withstand periods of moisture stress during El Nino conditions.

Mulching is particularly useful during periods of high temperature and limited rainfall. It reduces evaporation, moderates soil temperature and helps maintain moisture around the root zone. Conservation of soil moisture should begin immediately after rainfall. Unnecessary disturbance of the soil should be minimized, and suitable intercultural practices should be adopted according to the crop.

PPFM – Making Farm Management More Precise

PPFM can be integrated into climate-resilient agriculture by emphasizing field observation, timely decision-making and need-based application of farm inputs. The fundamental concept is simple: do not apply an input merely because it is normally applied; apply it when the crop and field actually require it.

Under uncertain climatic conditions, farmers should **regularly monitor the overall health and field condition of the crop.** This includes observing **soil moisture status, crop growth and colour, root development, nutrient deficiency symptoms, pest and disease incidence, weed growth, prevailing weather conditions, irrigation water availability and the crop growth stage**. Regular monitoring helps farmers identify problems at an early stage and make timely decisions on irrigation, nutrient application, weed management and plant protection. Such **need-based and timely interventions** can reduce input wastage, minimize crop stress and improve productivity under variable climatic conditions.

Based on these observations, decisions on irrigation, fertilizers, crop protection and other inputs can be modified. This approach helps reduce unnecessary expenditure and improves the efficiency of water, fertilizer and plant protection inputs.

Balanced Nutrient Management

High temperature and moisture stress can influence nutrient uptake and crop growth. Therefore, balanced nutrition is essential for maintaining crop vigour. Fertilizer application should preferably be based on soil test recommendations and crop requirements. Excess application of nitrogenous fertilizers should be avoided, particularly when water availability is uncertain.

Organic manures, biofertilizers and appropriate chemical fertilizers can be integrated as part of Integrated Nutrient Management (INM). Micronutrients should be applied when deficiency is identified or when recommended based on soil and crop conditions. Crop boosters and biostimulants should also be used judiciously and according to recommended practices rather than as a substitute for proper irrigation, nutrition and crop management.

Pest and Disease Management under Changing Weather

Changes in temperature and humidity can influence the population and activity of insect pests and pathogens. Therefore, farmers should not wait until pest populations become severe. Regular field scouting is essential. Farmers should inspect the crop at least once a week and identify early symptoms of pest or disease incidence.

An Integrated Pest Management (IPM) approach should be followed, including:

1. Regular monitoring of the crop
2. Use of resistant or tolerant varieties wherever available
3. Maintaining field sanitation
4. Use of biological control agents
5. Installation of appropriate traps
6. Conservation of natural enemies
7. Application of pesticides only when necessary and at the recommended dose

Thus, PPFM and IPM together can help farmers make crop protection decisions based on actual field conditions.

Special Attention to Horticultural and Perennial Crops

Perennial crops such as coconut require special attention during periods of prolonged heat and moisture stress because their production continues throughout the year. In coconut plantations, farmers should focus on maintaining adequate soil moisture through basin management, mulching, organic matter addition and efficient irrigation.

Drip irrigation can be adopted wherever feasible. Balanced nutrient management is also important. Recommended crop-specific technologies, including TNAU-recommended crop boosters or coconut tonic where appropriate, can be adopted based on technical recommendations. Intercropping with suitable crops can provide additional income and improve resource utilization, provided sufficient water and light are available.



Climate Information as a Farm Input

Weather information should be considered an agricultural input just like seed, fertilizer and irrigation water. Farmers should regularly follow reliable weather forecasts and advisories issued by agricultural universities, government departments and meteorological agencies. Rainfall forecasts can help farmers decide when to sow, irrigate, spray plant protection chemicals or postpone field operations.

For example, if rainfall is expected shortly, irrigation may be postponed. Similarly, spraying pesticides immediately before heavy rainfall may result in wastage and poor effectiveness.

Therefore:

"Weather information + field observation + timely action = better farm decisions."

Farm-Level El Nino Preparedness Strategy

A simple preparedness strategy can be followed at farm level:

Before the season:

Select suitable crops and varieties, assess water availability, arrange quality seed and plan alternative crops.

At sowing:

Use optimum sowing time, maintain proper seed rate and spacing, and ensure good soil moisture for establishment.

During crop growth:

Monitor soil moisture, irrigate efficiently, conserve moisture through mulching and maintain balanced nutrition.

During pest and disease occurrence:

Scout regularly, identify problems at an early stage and adopt IPM practices.

During prolonged dry spells:

Prioritize irrigation for critical crop stages, reduce unnecessary water use and adopt moisture-conservation practices.

Before harvest:

Monitor crop maturity and plan harvesting according to weather conditions to minimize losses.

Conclusion

El Ninois a climate phenomenon that farmers cannot control, but its agricultural impact can be managed through preparedness and appropriate farm decisions. The key is to move from reactive farming to proactive farming. PPFM-based farm management provides a practical framework for this transition by encouraging farmers to observe the field, understand crop requirements and apply resources only when and where they are needed. The future of climate-resilient agriculture lies not simply in using more inputs, but in using the right input, in the right quantity, at the right time and in the right place. Therefore, when El Ninobrings uncertainty, farmers should respond with preparedness rather than fear:

"Plan for the climate, protect the soil, save every drop of water, monitor the crop and act at the right time." Such an approach can help farmers reduce production risks, improve resource-use efficiency, maintain productivity and move towards a more climate-resilient and economically sustainable farming system.

Volume: 06 Issue No: 09

MICROPLASTICS IN AQUATIC ECOSYSTEMS: SOURCES, IMPACTS. AND MANAGEMENT

Article ID: AG-V06-I09-26

Reshmy E B [1]* andT. Varsha Chythanya[2]

[1]Department of Aquatic Environment and Management

Kerala University of Fisheries and Ocean studies, Panangad P.O, Kochi, Kerala, India.

[2]Department of Fish Pathology and Health Management, Tamilnadu Dr.J.Jayalalitha Fisheries University, Fisheries College and Research Institute,Thoothukudi, Tamil Nadu

*Corresponding Author: Reshmy E B

Abstract

Microplastics are plastic particles smaller than 5 mm that have become a pervasive contaminant in freshwater, estuarine, and marine ecosystems. They originate from the fragmentation of larger plastic debris and from primary sources such as microbeads, synthetic fibers, and industrial pellets. Due to their small size, microplastics are easily transported by rivers, currents, and atmospheric processes, leading to widespread distribution in aquatic environments. Numerous studies have demonstrated that microplastics can be ingested by plankton, invertebrates, fish, and marine mammals, causing physical injury, reduced feeding efficiency, altered growth, and reproductive impairment. In addition, microplastics can adsorb toxic chemicals such as heavy metals and persistent organic pollutants, thereby acting as vectors for contaminant transfer through food webs. Their accumulation in commercially important fish and shellfish raises concerns about ecological health and potential human exposure through seafood consumption. Effective management requires a combination of source reduction, improved waste management, wastewater treatment upgrades, public awareness, and policy interventions. This review examines the major sources, distribution patterns, ecological effects, trophic transfer, monitoring methods, and management strategies associated with microplastics in aquatic ecosystems.

Keywords: Microplastics, Aquatic Ecosystems, Plastic Pollution, Biodiversity, Water Quality, Marine Environment, Freshwater Systems, Food Web, Waste Management

1. Definition and Classification of Microplastics:

Microplastics are plastic particles smaller than 5 mm and can be divided into primary and secondary microplastics. Primary microplastics are made intentionally in small sizes for products like cosmetics, industrial abrasives, and resin pellets. Secondary microplastics come from the breakdown of larger plastic items due to ultraviolet radiation, mechanical wear, and biological processes. Common types include polyethylene, polypropylene, polystyrene, polyethylene terephthalate, and polyvinyl chloride. Research published in marine pollution journals shows that most particles found in water come from secondary microplastics, as discarded plastic waste breaks down extensively.

Classification also depends on shape, including fibers, fragments, films, pellets, and foams. Fibers from synthetic textiles are often dominant in freshwater samples, while fragments are usually abundant in coastal sediments. Understanding how microplastics are classified is important because different shapes and types of polymers behave differently in terms of movement, breakdown rates, and interactions with living organisms. Studies using Fourier-transform infrared spectroscopy and Raman spectroscopy have made it easier to identify polymer types, which helps in assessing their environmental distribution and ecological risks in rivers, lakes, estuaries, and oceans.

2. Sources of Microplastics in Aquatic Environments:

Microplastics enter water systems from various human activities. Domestic wastewater carries synthetic fibers lost during laundry, microbeads from personal care products, and broken plastic particles from household use. Industrial sources include plastic manufacturing plants, losses of resin pellets, and textile processing facilities. Urban runoff brings in fragments from packaging, road dust, tire wear, and litter. Agricultural fields add plastic mulch residues and particles from sewage sludge used as fertilizer. Research from river basin studies shows that wastewater treatment plants are significant sources because they receive large amounts of contaminated wastewater. Although treatment processes can remove many particles, millions of microplastics may still enter waterways each day. In coastal areas, tourism, fishing, and maritime activities add more plastic debris that eventually breaks down into microplastics. Wind can also transport fibers and particles, depositing them in remote lakes and marine regions. The variety of sources makes it hard to manage the issue and highlights the need for integrated policies that address plastic production, use, waste collection, and treatment across urban and rural areas.

3. Distribution in Freshwater, Estuarine, and Marine Systems: Microplastics are now found in nearly all aquatic environments, from mountain streams to deep-sea sediments. Freshwater rivers transport land-based plastic pollution toward estuaries and oceans. Studies in large river systems show high concentrations near urban areas and industrial sites. Estuaries often collect microplastics due to tidal mixing, changes in salinity, and sediment settling. In marine environments, microplastics are present at the surface, throughout the water column, and in sediments. Ocean currents gather floating particles in subtropical gyres, while heavier polymers settle on the ocean floor. Research in coastal regions of India, Europe, and North America shows significant differences based on population density, tourism levels, and waste management practices. Seasonal rainfall and river flow can also change microplastic amounts. Studies of sediments often find higher concentrations than in surface waters, as particles get caught in depositional areas. The widespread presence of microplastics shows their persistence and movement, making them a global environmental concern that calls for coordinated monitoring and management in both freshwater and marine ecosystems.

4. Interaction with Aquatic Organisms: Aquatic organisms encounter microplastics by eating, filtering, breathing, or coming into contact with them. Zooplankton, bivalves, crustaceans, and fish often mistake microplastic particles for food because of their size and appearance. Experimental studies show that consuming microplastics can decrease feeding efficiency by taking up space in the digestive system and creating a feeling of fullness. Filter-feeding organisms like mussels and oysters can accumulate microplastics in their digestive tissues and gills. Fish exposed to microplastics have shown changes in swimming behavior, slower growth, and shifts in energy use. Some studies also report inflammation, oxidative stress, and tissue damage after prolonged exposure. The severity of these effects depends on particle size, shape, concentration, and polymer type. Fibers can irritate more than smooth spherical particles, and very small particles can enter biological tissues more easily. Research on young fish reveals that larvae are especially vulnerable due to their high feeding rates and developing systems. These findings suggest that microplastics can impact individual health and possibly affect population dynamics in heavily polluted aquatic environments.

5. Chemical Contaminants Associated with Microplastics: Microplastics can carry various environmental pollutants. Their surfaces easily absorb persistent organic pollutants, such as polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and certain pesticides. Heavy

metals like lead, cadmium, copper, and zinc have also been found on microplastic particles in polluted waters. Laboratory experiments show that the ability to absorb chemicals varies depending on polymer type, particle size, surface texture, and environmental factors like salinity and temperature. When organisms eat contaminated particles, there is a chance for pollutants to be released in the digestive system, increasing internal exposure. Besides absorbed pollutants, many plastics contain additives like plasticizers, flame retardants, stabilizers, and colorants that can leach into surrounding tissues. Ecotoxicology studies have noted increased toxic effects when organisms are exposed to both microplastics and chemical pollutants at the same time. This combined exposure can result in oxidative stress, hormone disruption, and reproductive issues. The role of microplastics in transporting contaminants remains a key area of research, but current evidence suggests that they add to the mix of pollutants harming aquatic ecosystems.

6. Trophic Transfer and Bioaccumulation: Microplastics can travel through aquatic food webs when prey containing these particles are eaten by predators. For instance, zooplankton that ingest microplastics may pass them on to small fish, which are then consumed by larger predatory species. Laboratory feeding studies have confirmed this transfer happens across multiple levels of the food web, such as from mussels to crabs and from smaller fish to larger ones. While evidence of true bioaccumulation is limited, ongoing dietary exposure can lead to higher concentrations within organisms over time. Research on commercially important fish has found microplastics in their digestive tracts, gills, and sometimes other tissues. The presence of microplastics in seafood raises concerns about human exposure through eating fish. Researchers stress that particle size matters, as smaller particles are more likely to pass biological barriers and remain in tissues. Trophic transfer also increases the risk of moving associated pollutants through the food web. Understanding these pathways is important for managing fisheries, as fish caught for food may indicate levels of environmental contamination. More research is needed to determine the long-term effects of microplastic transfer on ecosystems and human health.

7. Effects on Fish and Fisheries Resources: Fish are one of the most studied groups in microplastic research due to their ecological and economic value. Field surveys have reported microplastic consumption in freshwater, estuarine, and marine fish species around the world. Experimental studies suggest that exposure may lower feeding efficiency, hinder growth, alter metabolic processes, and affect reproductive success. Histological studies have found signs of intestinal inflammation, damage to tissues, and oxidative responses in certain species. Changes

in behavior, such as less ability to avoid predators and altered swimming, have also been noted in lab tests. Early developmental stages seem especially sensitive, with larvae showing decreased survival rates and abnormal development when exposed to high levels of microplastics. For fishery resources, these effects could impact productivity, recruitment, and overall ecosystem health. Contaminated environments can also affect aquaculture operations, particularly when water sources receive untreated urban or industrial discharges. Researchers recommend integrating microplastic monitoring in fisheries assessments to evaluate environmental quality and potential risks to seafood safety. Thus, protecting fish habitats from plastic pollution is crucial for maintaining sustainable fisheries and ensuring food security in both coastal and inland communities.

8. Monitoring and Analytical Techniques: Effective monitoring of microplastics is crucial for assessing environmental pollution and evaluating management efforts. Sampling methods differ by habitat and include using plankton nets for surface water, grab samplers for sediment, and filtration systems for wastewater. After samples are collected, they often undergo density separation, the digestion of organic matter, and microscopic examination. However, visual identification can be misleading since natural fibers and particles can look like plastics. Advanced techniques like Fourier-transform infrared spectroscopy, Raman spectroscopy, pyrolysis-gas chromatography-mass spectrometry, and scanning electron microscopy provide more accurate identification of polymers. Research institutions are increasingly adopting standardized methods to improve comparability among studies. Quality assurance measures, including procedural blanks and contamination controls, are vital since airborne fibers can compromise samples during processing. Recent advances in automated imaging and machine learning have sped up and improved the accuracy of particle classification. Monitoring programs that examine water, sediment, biota, and wastewater together offer a thorough understanding of microplastic sources and movement. Establishing consistent methods remains a top priority for generating reliable data to support environmental management and policy decisions.

9. Wastewater Treatment and Management Strategies: Wastewater treatment plants are key in controlling the release of microplastics into aquatic environments. Primary treatment removes larger particles through screening and sedimentation, while secondary biological treatment further lowers microplastic loads.Advanced tertiary processes like membrane filtration, dissolved air flotation, and rapid sand filtration are more efficient in particle removal. However, particles

usually remain in the treated effluent and sludge even after employing these processes. Studies have demonstrated that in advanced wastewater treatment plants, particle removal could reach 90% and above, but since huge volumes of wastewater are produced every day, the number of particles that may eventually end up in the receiving water is not negligible. Therefore, appropriate management requires application of technological and source reduction techniques. Shedding of synthetic fibers could be reduced through the development of better designed textiles, prohibition of some types of microbeads, promotion of reusable materials and improved solid waste management infrastructure. Public campaigns on responsible waste disposal and reduction in plastic consumption could also play an important role in the prevention of microplastics release into environment. Proper management of nets, ropes, and plastic items used in aquaculture and fisheries industry could help to reduce local contamination. The combination of regulatory requirements, collaboration with industries, behavior change and improvement of infrastructure is considered to be the most effective strategy to reduce microplastic pollution.

10. Policy and Future Research Needs:

Many countries have introduced policies targeting plastic pollution, including restrictions on single-use plastics and bans on microbeads in cosmetic products. International initiatives under the United Nations Environment Programme and regional marine conventions have emphasized the need for coordinated action. However, regulations specifically addressing microplastics remain uneven across jurisdictions. Future policies should incorporate lifecycle approaches that consider plastic production, design, use, recycling, and disposal. Research priorities include understanding the fate of nanoplastics, evaluating long-term ecological impacts, developing standardized monitoring protocols, and assessing human exposure through seafood and drinking water. There is also a need for improved models that predict transport and accumulation in different aquatic environments. Emerging biodegradable materials require careful evaluation to determine whether they reduce or simply alter microplastic formation. Collaboration among scientists, policymakers, industry, and local communities will be essential for translating research findings into practical management actions. As evidence continues to grow, microplastic pollution is increasingly recognized as a significant component of global aquatic environmental management and a critical challenge for achieving sustainable use of freshwater and marine resources.

Conclusion

Microplastics have emerged as one of the most widespread and persistent pollutants in aquatic ecosystems. Their presence in rivers, lakes, estuaries, coastal waters, and deep-sea sediments demonstrates the extensive reach of plastic contamination. Research from journals and scientific publications consistently shows that microplastics originate from both primary and secondary sources and are transported through complex hydrological and atmospheric pathways. Aquatic organisms across multiple trophic levels ingest these particles, leading to physical stress, altered feeding behavior, reduced growth, and reproductive impairment. The ability of microplastics to adsorb toxic chemicals further increases their ecological significance by facilitating contaminant transfer through food webs. Although wastewater treatment technologies can remove a large proportion of particles, complete elimination remains difficult, emphasizing the importance of source reduction and improved waste management. Effective control of microplastic pollution requires integrated strategies that combine policy measures, industrial responsibility, public awareness, sustainable product design, and advanced treatment technologies. Continued monitoring using standardized analytical methods is essential for assessing trends and evaluating management success. Future research should focus on the long-term effects of microplastics and nanoplastics on aquatic biodiversity and human health. Protecting aquatic ecosystems from microplastic contamination is therefore crucial for maintaining ecological integrity, fisheries sustainability, and environmental quality.

References

1. Andrady, A. L. (2011). Microplastics in the marine environment. Marine Pollution Bulletin, 62(8), 1596–1605.
2. GESAMP. (2015). Sources, fate and effects of microplastics in the marine environment: A global assessment. Reports and Studies No. 90.
3. Li, J., Liu, H., & Chen, J. P. (2018). Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. Water Research, 137, 362–374.
4. Rochman, C. M. (2018). Microplastics research—from sink to source. Science, 360(6384), 28–29.
5. Thompson, R. C., et al. (2004). Lost at sea: Where is all the plastic? Science, 304(5672), 838.

6. Wright, S. L., & Kelly, F. J. (2017). Plastic and human health: A micro issue? Environmental Science & Technology, 51(12), 6634–6647.
7. Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013). The physical impacts of microplastics on marine organisms: A review. Environmental Pollution, 178, 483–492.
8. UNEP. (2021). From Pollution to Solution: A Global Assessment of Marine Litter and Plastic Pollution. United Nations Environment Programme.
9. Browne, M. A., et al. (2011). Accumulation of microplastic on shorelines worldwide: Sources and sinks. Environmental Science & Technology, 45(21), 9175–9179.
10. Arthur, C., Baker, J., & Bamford, H. (2009). Proceedings of the International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris. NOAA Technical Memorandum.

Volume: 06 Issue No: 09

INCREASING PRODUCTIVITY IN PULSES THROUGH IMPROVED CROP MANAGEMENT TECHNOLOGIES

Article ID: AG-V06-I09-27

***S. Krishnakumar and M. Ramasubramanian**

Krishi Vigyan Kendra, TNAU, Aruppukottai -626701, Virudhunagar District, Tamil Nadu, India

*Corresponding Author: S. Krishnakumar

Introduction

Pulses are cultivated extensively in Madurai district. For example, blackgram is cultivated in about 1,225 ha, while redgram is cultivated in about 2,738 ha. However, farmers often obtain lower yields due to inadequate adoption of improved crop management practices. By following the recommended technologies given below, farmers can increase pulse productivity and profitability.

1. Improved varieties

- Blackgram – VBN 8, VBN 11, VBN 12
- Greengram – VBN 4, VBN 5, CO 8
- Redgram (Pigeonpea) – CO 8, VBN 3, VBN 4
- Chickpea (Bengal Gram) – CO 4, JG 11
- Horsegram – Paiyur 2, CRIDA

2. Seed Treatment

Treat the seed before sowing with 4 g of Trichoderma viride per kg of seed or 10 g of Thiram per kg of seed. The treated seeds can also be inoculated with suitable beneficial biofertilizers such as Rhizobium. If seed treatment is not carried out, apply 4 packets of Rhizobium (800 g/acre) along with 4 packets of phosphobacteria (800 g/acre). Mix the biofertilizers with 25 kg of FYM and 25 kg of soil and apply them in the field before sowing.

3. Weed Management

For effective early weed control, apply Pendimethalin 0.8 litre/acre mixed with 200 litres of water as a pre-emergence spray on the third day after sowing. At about 30 days after

sowing, remove the remaining weeds by hand weeding or inter-cultivation.

4. Integrated Nutrient Management

For irrigated pulses

Where the previous crop was a rice crop, apply approximately:

- Urea – 14 kg/acre
- DAP – 43 kg/acre
- MOP – 17 kg/acre
- Gypsum – 4 kg/acre

For rainfed pulses

Apply:

- Urea – 7 kg/acre
- DAP – 22 kg/acre
- MOP – 8 kg/acre

For both rainfed and irrigated pulse crops, foliar application of DAP @ 20 g/litre of water (2 kg/100 litres) is recommended. Spray during the flowering stage and again 15 days later.

Foliar Nutrient Application – TNAU Pulse Wonder

TNAU Pulse Wonder is a crop-specific foliar nutrient formulation recommended for improving the growth, flowering, pod setting and yield of pulse crops. Dissolve 2 kg of TNAU Pulse Wonder in 200 litres of water and spray uniformly over the crop. First spray – Flowering stage: Apply when the crop enters the active flowering stage to support healthy flowering and reproductive growth. Second spray – Pod-setting stage: Repeat the spray during pod formation/pod-setting stage to support better pod development and grain filling. TNAU Pulse wonder foliar spray will promotes vigorous crop growth and healthy foliage, supports profuse and uniform flowering, improves flower retention and pod setting, helps reduce premature flower and pod shedding, supports better pod development and seed filling, contributes to improved seed yield and quality of seed.

5. Insect Pest Management

Pod borer management

To monitor and manage pod borers, install pheromone traps @ 5 traps/acre and bird perches @ 20/acre.

When pest incidence is noticed, spray Indoxacarb 250 ml/acre by mixing it with 250 litres of water.

Management of sucking insects

For monitoring sucking pests, install yellow sticky traps @ 5 traps/acre, adjusting the height according to the crop canopy. For botanical pest management, mix neem oil @ 200 ml in 10 litres of water along with a suitable soap solution and spray thoroughly over the crop.



Yellow vein mosaic virus



Aphids and Jassids



Blackgram (VBN 11)



Greengram (CO 8)



TNAU Pulse wonder

5. Disease Management

Yellow Mosaic Disease

Yellow mosaic disease initially appears as irregular yellow spots and patches on young leaves, which gradually spread over the leaf surface. The disease is mainly transmitted by the whitefly, *Bemisia tabaci*.

The following measures are recommended:

- Use quality, disease-free seeds.
- Maintain the field free from weeds, which can act as alternate hosts.
- Monitor the crop regularly for whitefly infestation.
- Spray Thiamethoxam @ 320 ml/acre at 30 and 45 days after sowing, as recommended.

Volume: 06 Issue No: 09

RECOVERY AND VALORIZATION OF PLANT PROTEINS FROM AGRO-INDUSTRIAL WASTE FOR SUSTAINABLE FOOD APPLICATIONS

Article ID: AG-V06-I09-28

***Amuthaselvi.G, R.Arulmari and P.Preetha**

Department of Food Process Engineering, Agricultural Engineering College & Research Institute, Tamil Nadu Agricultural University, Coimbatore-3, Tamil Nadu, India

*Corresponding Author: Amuthaselvi.G

Introduction

The rapid growth of the world population, increasing demand for protein-rich foods, pressure on agricultural resources and growing environmental concerns have created a strong need for sustainable sources of dietary protein. Protein is an essential macronutrient required for growth, tissue repair, enzyme and hormone synthesis, immune functions and maintenance of physiological activities. Conventional protein sources such as meat, milk and eggs are nutritionally valuable, but their production is associated with considerable requirements for land, water, feed and energy. Consequently, increasing attention has been directed towards plant proteins as alternative and complementary sources of dietary protein. At the same time, agricultural and food-processing industries generate enormous quantities of residues and by-products. These materials are often rich in protein, carbohydrates, dietary fibre, lipids, minerals and bioactive compounds, but a substantial proportion is discarded or utilized in relatively low-value applications. The recovery of proteins from these materials provides an opportunity to simultaneously address food waste, resource utilization and the growing demand for sustainable protein ingredients.

Agro-industrial residues should not always be regarded as waste because many of them contain significant concentrations of valuable nutrients and functional components. Oilseed cakes, cereal bran, pulse-processing residues, soybean okara, fruit seeds, vegetable residues and other processing streams can serve as potential sources of plant proteins. The conversion of these materials into protein concentrates, protein isolates or protein hydrolysates represents an

important strategy for increasing the efficiency of agricultural production. Protein recovery can also reduce the environmental burden associated with disposal and provide additional revenue for agricultural and food-processing industries. Therefore, the valorization of protein-rich agricultural residues has become an important research area within the concepts of circular economy, sustainable food production and biorefinery development (Kamal et al., 2021; Contreras et al., 2019).

The concept of plant protein recovery from agro-industrial residues is particularly important in developing countries where large quantities of agricultural commodities are processed but a significant proportion of the resulting by-products remains underutilized. In countries such as India, the processing of groundnut, sesame, sunflower, soybean, pulses, cereals, fruits and vegetables produces substantial quantities of protein-containing residues. Appropriate technologies can be employed to recover proteins from these materials and convert them into ingredients for human nutrition. This approach can create a link between agricultural production, food processing and sustainable food manufacturing. Furthermore, the utilization of locally available residues can reduce dependence on imported protein ingredients and contribute to rural employment and income generation.

2. Agro-Industrial Waste as a Source of Plant Protein

Agricultural and food-processing residues contain a wide range of nutrients, but their composition varies depending on the crop, cultivar, maturity, growing conditions and processing operation. Protein-rich residues are particularly attractive because proteins can be isolated and converted into higher-value ingredients. Oilseed cakes and meals are among the most important protein-rich by-products because oil extraction removes a major portion of the lipid fraction and consequently increases the relative concentration of protein. Groundnut cake, sesame cake, sunflower meal, soybean meal, rapeseed meal, mustard cake, coconut cake and other oilseed residues can therefore be considered potential sources of plant protein.

Oilseed cakes are traditionally used as animal feed because of their high protein content. However, proteins recovered from these materials may have greater economic value when processed into food-grade ingredients. The recovery process generally involves grinding, defatting if required, protein extraction, separation of insoluble materials, precipitation or membrane concentration, washing, neutralization and drying. The resulting protein concentrate or isolate can then be characterized for nutritional and functional properties. Depending on the

extraction process, the protein content of the final ingredient can be considerably higher than that of the original raw material.

Deoiled groundnut cake is one of the particularly promising sources of plant protein. Groundnut is widely cultivated and processed for edible oil, resulting in the generation of groundnut cake as a major by-product. The removal of oil leaves a protein-rich material containing proteins, fibre, minerals and residual bioactive compounds. Protein from deoiled groundnut cake can be extracted using alkaline solubilization and isoelectric precipitation. The recovered protein can potentially be utilized in bakery products, protein-rich snacks, beverages and plant-based meat analogues. Recent research has also explored high-intensity ultrasound as a method for modifying groundnut protein isolates and improving their functional characteristics (Rodríguez Rivera et al., 2025).

Sesame cake is another potentially valuable protein source. Sesame seeds contain significant amounts of protein, and the residue remaining after oil extraction retains much of this protein. Sesame proteins can be recovered through alkaline extraction, enzymatic treatment or other fractionation processes. The presence of phenolic compounds, however, may influence the colour and sensory characteristics of the resulting protein ingredient. Appropriate purification may therefore be required depending on the intended application.

Sunflower meal and cake also contain considerable amounts of protein. Sunflower protein has attractive nutritional and functional characteristics, although phenolic compounds and pigments may affect the colour and sensory quality of the extracted protein. Rapeseed and mustard cakes are similarly rich in protein but require careful consideration of antinutritional compounds and undesirable components. Soybean processing residues, particularly okara, are another important resource. Okara contains protein, dietary fibre and residual lipids but has high moisture content and is highly susceptible to microbial spoilage. Stabilization and protein recovery can therefore significantly improve its utilization.

3. Cereal and Pulse Processing Residues

Cereal processing generates several protein-containing fractions, including bran, germ and milling residues. Rice bran is an important by-product of rice milling and contains proteins, lipids, dietary fibre, minerals and bioactive compounds. Although rice bran protein may not be as concentrated as some oilseed proteins, the enormous quantity of rice processed globally makes rice bran an attractive raw material for protein recovery. Furthermore, rice bran can be

considered as a multiproduct raw material from which oil, protein, dietary fibre and bioactive compounds can be recovered. Wheat bran is another abundant agricultural by-product. It contains protein, dietary fibre, minerals and phenolic compounds. Protein recovery from wheat bran is complicated by the strong association of proteins with cell-wall components. Enzymatic and physical pretreatments can be used to improve protein release. The resulting protein-rich fractions can potentially be used in bakery products and protein-enriched foods.

Pulse-processing industries generate broken grains, hulls and other milling fractions. Pea, chickpea, lentil, soybean and bean residues are particularly interesting because legumes generally contain higher protein concentrations than many cereals. Pulse proteins are already widely used in the production of protein concentrates and isolates. The use of processing residues provides an opportunity to further improve resource utilization.

Soybean okara deserves particular attention because it is produced in large quantities during soy milk and tofu manufacturing. Fresh okara contains considerable moisture and is therefore highly perishable. Drying or stabilization is necessary before long-term storage. Okara contains protein as well as substantial dietary fibre, making it possible to develop multifunctional ingredients. Protein recovered from okara may be incorporated into bakery products, snacks, meat analogues and other foods.

4. Fruit and Vegetable Processing Residues as Protein Sources

Fruit and vegetable processing residues are increasingly being investigated for the recovery of proteins and other valuable components. Seeds and kernels from fruits such as jackfruit, mango, watermelon and pumpkin contain appreciable quantities of protein and can be converted into protein-rich ingredients. These materials are often discarded during processing despite their nutritional value. For example, jackfruit seeds contain proteins, starch and other nutrients and can potentially be processed into flour and protein-rich fractions.

Watermelon and pumpkin seeds are also promising sources of plant protein. Their proteins can be extracted after drying, grinding and defatting. Because these seed materials also contain valuable lipids and bioactive compounds, an integrated extraction process could be developed to recover multiple components. Such an approach would increase the economic value of the raw material compared with a process designed only for protein extraction.

Tomato-processing residues also contain seeds and skin fractions that may be further utilized. Although their protein concentration may be relatively lower than that of oilseed cakes,

their large production volume makes them important candidates for valorization. Protein recovery from fruit and vegetable residues should be combined with the recovery of other valuable compounds such as phenolics, pigments, dietary fibre and oils to maximize overall resource utilization.

5. Preparation and Pretreatment of Raw Materials

The efficiency of protein extraction is strongly influenced by raw-material preparation. Initially, the agricultural residue should be cleaned to remove soil, stones, dust, metal particles and other foreign materials. Cleaning is particularly important when the final product is intended for human consumption. The material is subsequently dried to reduce moisture content and prevent microbial deterioration. Drying can be performed using tray drying, hot-air drying, fluidized-bed drying, vacuum drying or other appropriate techniques.

After drying, the material is milled to reduce particle size. Grinding increases surface area and improves the contact between the raw material and extraction medium. However, excessively fine particles may increase energy consumption and make centrifugation or filtration more difficult. Therefore, optimization of particle size is necessary.

Defatting is an important pretreatment for oilseed-derived residues. Residual oil can interfere with protein extraction and may contribute to oxidative deterioration during storage. Defatting can be performed by mechanical pressing, solvent extraction or other suitable techniques. For food applications, the choice of method should consider safety, cost, environmental impact and residual solvent limits.

Pretreatment can also include soaking, thermal treatment, enzymatic treatment, fermentation or ultrasound. These methods may disrupt cellular structures and improve the accessibility of proteins. The selection of pretreatment should depend on the characteristics of the raw material and the desired properties of the final protein ingredient.

6. Conventional Alkaline Extraction

Alkaline extraction followed by isoelectric precipitation is one of the most widely used approaches for obtaining plant protein isolates. During alkaline extraction, the ground raw material is mixed with water and the pH is adjusted to an alkaline condition. Proteins become more soluble under appropriate alkaline conditions because their electrical charge increases, resulting in greater interaction with water. Insoluble components such as fibre and some starch fractions remain in the solid phase.

The suspension is subsequently centrifuged or filtered. The insoluble residue is separated, while the protein-rich supernatant is collected. The pH of the supernatant is then adjusted towards the isoelectric point of the protein. At this pH, the net electrical charge of the protein approaches zero and electrostatic repulsion decreases, causing the protein molecules to aggregate and precipitate. The precipitated protein is separated through centrifugation and washed to remove soluble impurities.

The recovered protein can then be neutralized and dried. The process conditions, including pH, extraction temperature, extraction time and solid-to-liquid ratio, have significant effects on protein recovery and purity. Excessive alkalinity and prolonged extraction can result in protein denaturation and undesirable changes in functionality. Consequently, optimization is necessary to obtain high protein recovery while maintaining good functional characteristics (Boye et al., 2010; Kamal et al., 2021).

7. Dry Fractionation

Dry fractionation is an alternative method for producing protein-rich ingredients without extensive water consumption. In this process, the raw material is dried and milled, followed by physical separation based on differences in particle size, density and aerodynamic behaviour. Air classification is one of the commonly investigated methods for producing protein-rich fine fractions.

The major advantage of dry fractionation is its lower environmental impact compared with conventional wet extraction. It requires less water and generates less wastewater. It also reduces the requirement for chemical reagents and can help preserve the native structure of plant proteins. However, the protein concentration achieved through dry fractionation is generally lower than that obtained through wet extraction. Dry fractionation may therefore be particularly suitable for producing protein-enriched flour or moderately concentrated protein ingredients rather than highly purified isolates (Schutyser et al., 2015).

8. Enzyme-Assisted Extraction

Enzyme-assisted extraction can improve protein recovery by breaking down structural components surrounding proteins. Plant cell walls contain cellulose, hemicellulose and pectin, which can limit the release of intracellular proteins. Enzymes such as cellulase, pectinase and hemicellulase can degrade these structural polysaccharides and facilitate protein release. Proteases can also be used to partially hydrolyse proteins and generate protein hydrolysates.

Controlled hydrolysis can improve protein solubility and digestibility and may generate peptides with potentially useful biological activities. However, excessive hydrolysis can reduce certain functional properties and may result in bitter taste. Therefore, enzyme concentration, pH, temperature and treatment duration should be carefully controlled.

Enzyme-assisted extraction has the advantage of operating under relatively mild conditions and potentially reducing the requirement for strong chemical treatments. However, enzyme cost and the time required for treatment remain important considerations for industrial application.

9. Ultrasound-Assisted Extraction

Ultrasound-assisted extraction is an emerging technology that can improve the recovery of proteins from plant materials. High-intensity ultrasound generates acoustic cavitation, in which microscopic bubbles form and collapse rapidly in the extraction medium. The resulting localized mechanical forces and turbulence can disrupt plant tissues and improve mass transfer. Ultrasound can increase the contact between the extraction medium and plant matrix and thereby improve protein release. The effectiveness of the process depends on ultrasonic power, treatment time, frequency, temperature, pH and solid-to-liquid ratio. Moderate ultrasound treatment may improve protein solubility and functional properties, while excessive treatment may cause aggregation or structural damage.

Ultrasound can also be applied after extraction to modify the properties of protein isolates. Changes in protein conformation, particle size and surface characteristics may influence emulsifying, foaming and water-binding properties. Therefore, ultrasound has considerable potential not only as an extraction technology but also as a protein modification technology.



10. Microwave-Assisted Extraction

Microwave-assisted extraction utilizes electromagnetic energy to rapidly heat the

extraction system. Microwaves interact with polar molecules and ions, resulting in rapid volumetric heating. This heating can disrupt plant structures and increase the rate of mass transfer, potentially reducing extraction time. The efficiency of microwave-assisted extraction depends on power, treatment time, moisture content, solvent composition and temperature. Excessive microwave treatment can cause protein denaturation and aggregation. Therefore, optimization is required to obtain maximum extraction efficiency without compromising protein quality.

11. Membrane Technology for Protein Concentration

Membrane separation is increasingly used in food processing because it enables concentration and purification under relatively mild conditions. Ultrafiltration can retain protein molecules while allowing smaller components such as salts, sugars and other soluble substances to pass through the membrane. Membrane technology can be integrated with conventional protein extraction to reduce the need for chemical precipitation. It can also provide a relatively continuous processing system. However, membrane fouling caused by proteins, lipids and other components remains a major challenge. Pretreatment and appropriate cleaning protocols are therefore necessary.

12. Nutritional Characterization of Recovered Protein

The nutritional value of recovered plant proteins should be evaluated through several parameters. Protein content is commonly determined using the Kjeldahl or Dumas method. Protein recovery is calculated based on the quantity of protein recovered relative to the amount present in the original raw material. Protein purity indicates the percentage of protein in the final product. Amino acid composition is particularly important for evaluating protein quality. Essential amino acids cannot be synthesized adequately by the human body and must therefore be supplied through the diet. Plant proteins differ in their amino acid profiles. Cereal proteins are often relatively limited in lysine, whereas some legume proteins may be relatively low in sulphur-containing amino acids. Protein blending can therefore be used to obtain a more balanced amino acid composition. Protein digestibility is another important factor. The digestibility of plant proteins can be reduced by structural characteristics and antinutritional factors. Processing techniques such as heating, fermentation, germination and enzymatic hydrolysis can sometimes improve digestibility.

13. Functional Properties of Recovered Plant Proteins

The functional properties of plant proteins determine their suitability for specific food applications. Protein solubility is particularly important in beverages and liquid food systems. A highly soluble protein can disperse readily in water and reduce sedimentation problems. Water-holding capacity is important for meat analogues, bakery products and protein-based gels. Proteins capable of retaining water can improve product yield, juiciness and texture. Oil-holding capacity is also important because it influences flavour retention and mouthfeel.

Emulsifying properties are essential when proteins are incorporated into products containing both oil and water. Proteins can migrate to the oil-water interface and form protective films around oil droplets. Therefore, emulsifying activity and emulsion stability are important characteristics for proteins intended for sauces, dressings and beverages. Foaming properties are important in bakery products, whipped foods and desserts. The ability of proteins to form and stabilize air-water interfaces depends on molecular flexibility, surface hydrophobicity and protein concentration. Processing conditions can significantly alter these properties. Gelation is another important property for food applications. Upon heating or other treatments, proteins may unfold and interact with one another to form three-dimensional networks. This property is particularly relevant to plant-based meat products and structured protein foods.

14. Antinutritional Factors

Although plant residues can provide valuable protein, some materials contain antinutritional factors. Phytates, tannins, oxalates, saponins and protease inhibitors are among the compounds that may interfere with nutrient utilization. Their concentrations depend on plant species, variety, maturity and processing history. Processing methods such as soaking, germination, fermentation, thermal treatment and enzymatic treatment can reduce certain antinutritional factors. However, the processing conditions should be carefully controlled because severe treatment may negatively affect protein functionality and nutritional quality. The reduction of antinutritional factors is particularly important when proteins recovered from agricultural residues are intended for human food applications. Comprehensive characterization should therefore include both nutritional components and potential antinutritional compounds.

15. Food Safety Considerations

Food safety is a critical requirement for converting agricultural waste into food-grade protein ingredients. Raw materials should be obtained from reliable sources and protected from

microbial contamination during collection, transportation and storage. High-moisture residues such as okara and fruit-processing residues are particularly susceptible to microbial growth and therefore require rapid stabilization.

Mycotoxin contamination is another important concern, particularly in oilseed-derived materials. Groundnut and other commodities can be susceptible to fungal contamination under inappropriate storage conditions. Aflatoxin control is therefore essential when groundnut-derived materials are intended for human consumption. Heavy metals, pesticide residues and other contaminants should also be monitored. Processing alone cannot necessarily eliminate all contaminants. Consequently, good agricultural practices, hygienic processing, appropriate storage and quality-control systems are necessary throughout the production chain. Allergenicity should also be considered. Proteins from groundnut, soybean and other allergenic plants can cause adverse reactions in susceptible individuals. Therefore, appropriate labelling, allergen control and segregation should be implemented when such proteins are used in commercial food products.

16. Modification of Recovered Proteins

Protein modification may be required to improve the functional characteristics of proteins recovered from agro-industrial residues. Physical modification techniques include heating, ultrasound, high-pressure processing, microwave treatment and extrusion. These methods can alter protein structure and interactions, thereby influencing solubility, emulsification, foaming and gelation. Enzymatic hydrolysis is another important method. Controlled hydrolysis can reduce protein molecular size and improve solubility and digestibility. Protein hydrolysates may also contain peptides with antioxidant or other biological activities. However, excessive hydrolysis can generate bitter peptides and reduce desirable functional properties.

Fermentation is an additional approach that may improve the nutritional and sensory properties of plant protein ingredients. Microbial fermentation can modify proteins and reduce certain antinutritional compounds. It may also produce desirable flavour compounds and improve digestibility.

17. Application in Plant-Based Meat Analogues

The development of plant-based meat analogues is one of the most promising applications of recovered plant proteins. Meat analogues are formulated to reproduce selected characteristics of conventional meat, including appearance, texture, flavour and nutritional

composition. Proteins are the principal structural components of these products and contribute to texture formation, water retention and gelation. Proteins recovered from oilseed cakes, pulse residues and cereal by-products can potentially be incorporated into meat analogue formulations. A typical formulation may contain protein, water, vegetable oil, starch, dietary fibre, hydrocolloids, flavour compounds and other ingredients. Extrusion processing is widely used because it can transform plant proteins into structured products with fibrous characteristics.

The quality of a meat analogue depends strongly on the functional properties of the protein ingredient. High water-holding capacity can improve juiciness, while emulsifying properties contribute to the stability of oil within the protein matrix. Protein-protein interactions during heating and extrusion contribute to the development of texture. Deoiled groundnut cake protein is particularly interesting for such applications because it is a protein-rich by-product that can be converted into a value-added food ingredient. However, blending groundnut protein with proteins from pulses or cereals may be necessary to improve amino acid balance and optimize texture. The final product should be evaluated for protein content, moisture, cooking yield, texture, colour, water-holding capacity, oil-holding capacity, sensory characteristics and storage stability.

18. Application in Bakery Products

Recovered plant proteins can be incorporated into bread, biscuits, cookies, crackers, cakes and other bakery products. Protein enrichment can improve nutritional value and increase the utilization of agricultural residues. However, protein addition may alter dough rheology, gluten interactions, water absorption, gas retention, product volume and texture. The level of protein incorporation must therefore be optimized. Excessive protein addition may produce dense products, darker colour or undesirable flavour. Appropriate blending with wheat flour or other ingredients can help maintain acceptable sensory and technological characteristics. Protein-rich agricultural residues can also be incorporated into extruded snacks and nutrition bars. Such products provide opportunities for developing high-protein foods while utilizing relatively inexpensive raw materials.

19. Application in Protein Beverages

Protein concentrates and isolates recovered from agricultural residues may be used in protein beverages and plant-based milk alternatives. For these applications, high solubility and dispersion stability are essential. Poorly soluble proteins can form sediments and produce an

undesirable mouthfeel. Protein modification through ultrasound, enzymatic hydrolysis or controlled heat treatment may improve solubility. Homogenization and pH adjustment can also influence the stability of protein-containing beverages. However, sensory characteristics must be carefully considered because some plant proteins possess characteristic beany, bitter or astringent flavours.

20. Protein Hydrolysates and Bioactive Peptides

Plant protein hydrolysates are produced through controlled enzymatic or chemical hydrolysis of proteins. Hydrolysis reduces protein molecular size and generates peptides of different molecular weights. These hydrolysates may have improved solubility and digestibility and may demonstrate biological activities in laboratory studies. Peptides derived from plant proteins have been investigated for antioxidant, antihypertensive, antimicrobial and other potential activities. However, laboratory observations should not automatically be considered evidence of human health benefits. Further in vivo and clinical studies are required to establish physiological effects.

The production of protein hydrolysates nevertheless provides an additional opportunity for increasing the value of agro-industrial residues. Such ingredients may have applications in specialized nutrition, functional foods and sports nutrition, subject to appropriate safety and regulatory evaluation.

21. Circular Economy and Biorefinery Concept

Protein recovery from agricultural waste fits strongly within the circular economy concept. In a conventional linear food system, agricultural resources are cultivated, processed and eventually discarded. In a circular system, valuable nutrients and components are recovered and reused, reducing waste and improving resource efficiency. A biorefinery approach can maximize the value of agro-industrial residues by recovering several products rather than only protein. For example, an oilseed cake could potentially provide protein, dietary fibre, phenolic compounds and residual oil. After these components are recovered, the remaining biomass may be used for animal feed, fermentation, bioenergy or other applications.

Such integrated utilization can significantly improve the economics of the process. The development of a biorefinery requires careful sequencing of extraction operations because the recovery of one component can influence the quality and yield of subsequent components.

22. Environmental Benefits

The recovery of plant proteins from agro-industrial waste can provide several environmental benefits. First, it reduces the quantity of organic residues requiring disposal. Second, it improves the efficiency of agricultural resources because more of the original biomass is converted into useful products. Third, replacing a portion of conventional animal protein with plant-derived protein may contribute to reducing resource requirements associated with livestock production, although the actual environmental benefit depends on the complete processing system.

Green extraction technologies can further reduce environmental impact. Dry fractionation reduces water use, while membrane processing can reduce chemical requirements. Enzyme-assisted and ultrasound-assisted extraction may also reduce processing severity. Life-cycle assessment should nevertheless be used to evaluate the actual environmental performance of each process because energy consumption, water use and chemical requirements can vary considerably.

23. Economic Potential

The economic potential of protein recovery depends on raw-material availability, protein concentration, extraction yield, processing cost, product quality and market demand. Agro-industrial residues are often inexpensive because they are generated as secondary streams. However, collection, transportation, drying, storage and processing can add significant costs. A successful commercial process must therefore maximize protein recovery while minimizing water, chemical, energy and labour requirements. Integrated processing can improve profitability by generating multiple products from the same raw material. For example, simultaneous recovery of protein, fibre and phenolic compounds can provide several revenue streams. Small-scale decentralized processing may also be suitable for agricultural regions where residues are generated seasonally. Such systems can reduce transportation costs and provide additional income opportunities for farmers and local processing industries.

24. Challenges and Limitations

Despite the significant potential, several challenges must be addressed before widespread commercialization of waste-derived plant proteins. Raw-material variability is one of the most important issues. Protein concentration and composition can vary according to crop variety, growing conditions, maturity and processing method. Standardization of raw materials is

therefore essential. Another challenge is maintaining protein functionality during extraction. Severe pH, high temperature and prolonged processing can increase protein recovery but may result in denaturation and aggregation. The optimum process must therefore balance yield, purity and functionality.

Off-flavours, undesirable colour and antinutritional compounds can also reduce consumer acceptance. Phenolic compounds and oxidation products may contribute to bitterness, astringency or dark colour. Additional purification and sensory optimization may therefore be required. The scalability of emerging technologies is another important limitation. Technologies such as ultrasound, pulsed electric field and microwave-assisted extraction have demonstrated promising results at laboratory scale, but their economic and technical feasibility at industrial scale must be established.

25. Future Research Opportunities

Future research should focus on developing integrated and environmentally sustainable processes for the recovery of proteins from agro-industrial residues. The combination of physical, chemical and biological techniques may provide better results than individual extraction methods. For example, ultrasound or pulsed electric field treatment could be used as a pretreatment to improve protein release, followed by alkaline extraction and membrane concentration.

The use of Response Surface Methodology can help optimize extraction conditions by evaluating the simultaneous effects of pH, temperature, extraction time, solid-to-liquid ratio and other variables. More recently, artificial intelligence and machine learning techniques have provided opportunities to predict extraction yield, protein functionality and process performance. Another promising area is the development of protein blends. Proteins from cereals, pulses and oilseeds can be combined to overcome limitations in amino acid composition and functional properties. Such blends could be particularly useful in plant-based meat analogues, protein beverages and nutritional foods.

Future studies should also focus on the complete characterization of recovered proteins using advanced analytical techniques such as SDS-PAGE, Fourier-transform infrared spectroscopy, differential scanning calorimetry, particle-size analysis, chromatography and mass spectrometry. These techniques can provide information about molecular structure, thermal stability, protein aggregation and functional behaviour.

Conclusion

The recovery of plant proteins from agro-industrial waste represents an important opportunity to address the growing demand for sustainable protein while reducing food-processing waste. Agricultural residues such as oilseed cakes, cereal bran, pulse-processing by-products, soybean okara and fruit seeds contain valuable proteins that can be converted into protein-rich ingredients through appropriate extraction and purification technologies. Among these materials, deoiled groundnut cake is particularly promising because of its availability and relatively high protein content.

Conventional alkaline extraction followed by isoelectric precipitation remains an effective approach for producing plant protein isolates, while dry fractionation, enzyme-assisted extraction, ultrasound-assisted extraction, microwave-assisted extraction, pulsed electric field and membrane separation offer opportunities to improve efficiency and reduce environmental impact. The recovered proteins should be evaluated not only for protein content and recovery but also for amino acid composition, digestibility, antinutritional factors, solubility, water-holding capacity, oil-holding capacity, emulsifying ability, foaming properties and gelation behaviour.

The successful utilization of recovered plant proteins in meat analogues, bakery products, beverages, snacks and protein hydrolysates can significantly increase the value of agricultural residues. An integrated biorefinery approach can further enhance sustainability by recovering protein together with fibre, phenolic compounds, oils and other valuable components. Nevertheless, issues related to raw-material variability, food safety, allergenicity, off-flavour, processing cost, functionality and industrial scalability must be addressed.

References

Kamal, H., Le, C. F., Salter, A. M., & Ali, A. (2021). Extraction of protein from food waste: An overview of current status and opportunities. *Comprehensive Reviews in Food Science and Food Safety, 20*(3), 2455–2475.

Contreras, M. M., Lama-Muñoz, A., Gutiérrez-Pérez, J. M., Espínola, F., Moya, M., & Castro, E. (2019). Protein extraction from agri-food residues for integration in biorefinery: Potential techniques and current status. *Bioresource Technology, 280*, 459–477.

Hadidi, M., Aghababaei, F., Gonzalez-Serrano, D. J., Goksen, G., Trif, M., McClements, D. J., & Moreno, A. (2024). Plant-based proteins from agro-industrial waste and by-products:

Towards a more circular economy. *International Journal of Biological Macromolecules, 261*, 129576.

Day, L. (2013). Proteins from land plants—Potential resources for human nutrition and food security. *Trends in Food Science & Technology, 32*(1), 25–42.

Boye, J., Zare, F., & Pletch, A. (2010). Pulse proteins: Processing, characterization, functional properties and applications in food and feed. *Food Research International, 43*(2), 414–431.

Schutyser, M. A. I., Pelgrom, P. J. M., van der Goot, A. J., & Boom, R. M. (2015). Dry fractionation for sustainable production of functional legume protein concentrates. *Trends in Food Science & Technology, 45*(2), 327–335.

Gorissen, S. H. M., Crombag, J. J. R., Senden, J. M. G., Waterval, W. A. H., Bierau, J., Verdijk, L. B., & van Loon, L. J. C. (2018). Protein content and amino acid composition of commercially available plant-based protein isolates. *Amino Acids, 50*, 1685–1695.

Loveday, S. M. (2019). Food proteins: Technological, nutritional and sustainability attributes of traditional and emerging proteins. *Annual Review of Food Science and Technology, 10*, 311–339.

Lam, A. C. Y., Can Karaca, A., Tyler, R. T., & Nickerson, M. T. (2018). Pea protein isolates: Structure, extraction and functionality. *Food Reviews International, 34*, 126–147.

McClements, D. J., & Grossmann, L. (2021). A brief review of the science behind the design of healthy and sustainable plant-based foods. *npj Science of Food, 5*, 17.

Rodríguez Rivera, Á. E., Ulloa, J. A., Urías Silvas, J. E., Ramírez Ramírez, J. C., & Resendiz Vazquez, J. A. (2025). Physicochemical, techno-functional, biochemical and structural characterization of a protein isolate from groundnut (*Arachis hypogaea* L.) paste treated with high-intensity ultrasound. *Food Chemistry, 464*, 141848.

Volume: 06 Issue No: 09

GREEN INVESTMENTS: HOW SUSTAINABLE AGRICULTURE IS CREATING NEW STOCK MARKET OPPORTUNITIES

Article ID: AG-VO6-I09-29

[*1]Sakimitha. M, [2]R. Vinoth and [3]J. Gokulakrishnan

[1]B.Sc. (Hons) Agriculture**,** Institute of Agriculture (IOA), Tamil Nadu Agricultural University, Kumulur, Trichy, Tamil Nadu, Inida

[2]Teaching Assistant (PBG), Institute of Agriculture (IOA), Tamil Nadu Agricultural University, Kumulur, Trichy, Tamil Nadu, India

[3]Associate Professor (PBG), Institute of Agriculture (IOA), Tamil Nadu Agricultural University, Kumulur, Trichy, Tamil Nadu, India

*Corresponding Author: **S**akimitha. M,

Abstract

Contribution long-term value for investors while supporting global sustainability goals Sustainable agriculture has become a major driver of global green investments, creating new opportunities for both environmental conservation and financial growth. As climate change, resource scarcity, and food security challenges intensify, investors are increasingly directing capital toward environmentally responsible agricultural practices and innovative Agritech solutions. The rapid expansion of Environmental, Social, and Governance (ESG) investing has further accelerated investments in precision agriculture, renewable energy, carbon farming, biological inputs, and digital farming technologies. These developments are reshaping agricultural value chains while generating attractive opportunities in global stock markets. This article examines the relationship between green investments and sustainable agriculture by exploring emerging investment trends, ESG-driven financial markets, climate-smart technologies, carbon credit mechanisms, government policies, and the growing role of Agritech companies. It also highlights India's potential as a leading destination for sustainable agricultural investments and discusses the challenges and prospects associated with green finance. The study

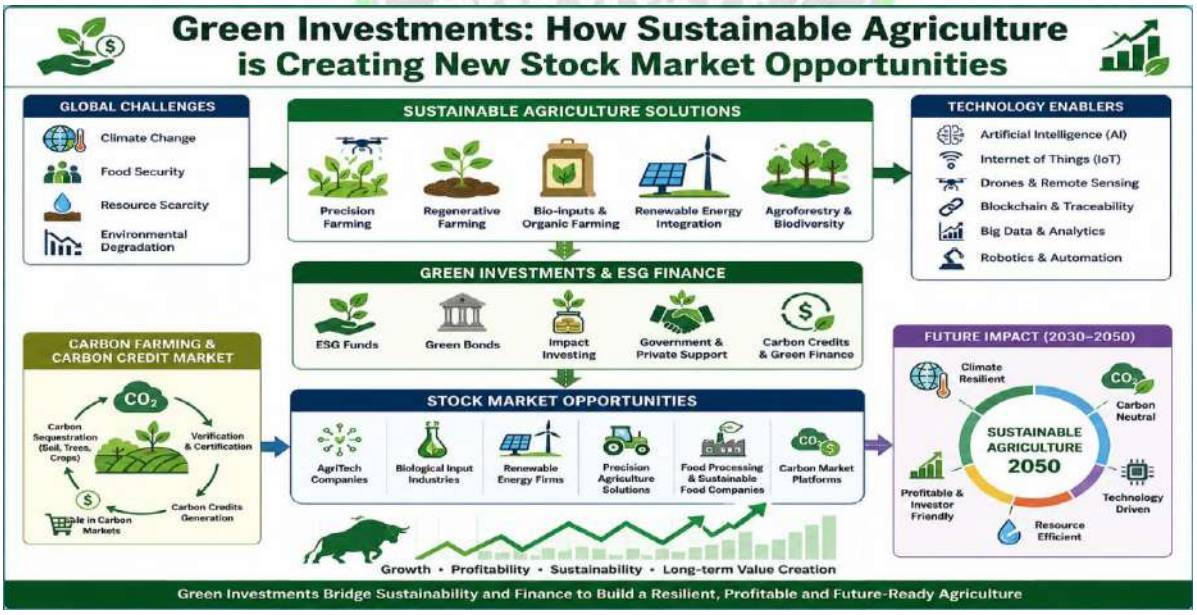
concludes that green investments are transforming agriculture into a resilient, technology-driven, and economically attractive sector.

Keywords: Green Investments; Sustainable Agriculture; ESG Investing; Agritech; Climate-Smart Agriculture; Stock Market; Green Finance; Carbon Credits; Renewable Energy.

Introduction

Agriculture is facing major challenges due to climate change, resource scarcity, environmental degradation, and increasing global food demand. These challenges have created the need for sustainable agricultural systems that improve productivity while protecting natural resources. Green investments have emerged as a powerful approach to support this transformation by directing financial resources toward environmentally responsible agricultural technologies and practices. The growing importance of Environmental, Social, and Governance (ESG) investing has encouraged investors to focus on companies involved in precision agriculture, renewable energy, biological inputs, carbon farming, and digital farming solutions.

Advancements in Artificial Intelligence (AI), Internet of Things (IoT), drones, and smart farming technologies are creating new opportunities for sustainable agriculture while attracting significant investment interest. India and other agricultural economies are increasingly adopting these innovations to improve climate resilience and farm profitability.



This article explores how sustainable agriculture is creating new stock market opportunities by examining green finance, ESG trends, Agritech innovations, carbon markets, investment opportunities, and future prospects. Green investments represent a pathway that connects

environmental sustainability with economic growth, shaping the future of global agriculture and financial markets.

Understanding Green Investments:

What are Green Investments?

Green investments are financial investments made in projects, companies, or technologies that promote environmental sustainability while generating long-term economic returns. Unlike conventional investments, green investments focus not only on profitability but also on reducing environmental impacts, conserving natural resources, and supporting sustainable development.

In agriculture, green investments finance innovative practices that improve productivity while protecting soil, water, biodiversity, and the climate. These investments help farmers adopt climate-smart technologies, renewable energy systems, efficient irrigation methods, biological crop protection, precision farming, and regenerative agricultural practices.

Green investments are increasingly supported by governments, institutional investors, venture capital firms, development banks, and private equity funds because they contribute to food security, rural development, climate resilience, and long-term economic growth.

Evolution of Green Investments in Agriculture

The concept of green investment has evolved significantly over the past three decades. Initially, environmental investments mainly focused on pollution control and renewable energy. However, increasing concerns about climate change, food security, biodiversity loss, and sustainable resource management have expanded green investments into the agricultural sector.

Several global developments have accelerated this transition:

- Adoption of the **United Nations Sustainable Development Goals (SDGs)** in 2015, particularly **SDG 2 (Zero Hunger)**, **SDG 12 (Responsible Consumption and Production)**, and **SDG 13 (Climate Action)**.
- The **Paris Climate Agreement**, which encouraged countries to reduce greenhouse gas emissions and promote climate-resilient agriculture.
- Rapid growth of **Environmental, Social, and Governance (ESG)** investing.
- Advances in digital agriculture, Artificial Intelligence (AI), precision farming, and renewable energy technologies.

Today, sustainable agriculture is considered one of the fastest-growing sectors for green finance and long-term investment.

Principles of Green Investments:

Green investments are guided by several key principles that ensure both environmental and economic sustainability:

1. **Environmental Protection** – Reducing pollution, greenhouse gas emissions, and environmental degradation.
2. **Efficient Resource Use** – Optimizing water, energy, fertilizers, and land resources.
3. **Climate Resilience** – Supporting agricultural systems that can adapt to climate change.
4. **Economic Sustainability** – Generating stable long-term financial returns while minimizing risks.
5. **Social Responsibility** – Improving farmers' livelihoods, rural employment, and food security.
6. **Innovation and Technology** – Promoting advanced technologies that improve agricultural productivity sustainably.

Major Types of Green Investments in Sustainable Agriculture:

Investment Area	Description	Benefits
Precision Agriculture	AI, IoT, GPS, drones, sensors	Higher productivity and lower input costs
Renewable Energy	Solar pumps, biogas, wind energy	Reduced energy costs and carbon emissions
Regenerative Agriculture	Soil restoration, cover crops, crop rotation	Improved soil health and carbon sequestration
Biological Inputs	Biofertilizers and biopesticides	Reduced chemical dependency
Water Management	Drip irrigation, smart irrigation systems	Water conservation and higher efficiency

Why Green Investments Matter in Agriculture

Agriculture depends heavily on natural resources, making it highly vulnerable to climate change and environmental degradation. Green investments enable farmers and agribusinesses to

adopt sustainable technologies that increase productivity while minimizing environmental impacts.

The major benefits include:

- Improved crop productivity through precision farming.
- Reduced production costs by optimizing resource use.
- Enhanced soil fertility and biodiversity.
- Lower greenhouse gas emissions.
- Increased resilience to droughts, floods, and climate variability.
- Better access to ESG funds and green financing.
- New revenue opportunities through carbon credit markets.

Global Green Investment Market and Emerging Stock Market Opportunities:

Global Green Investment Market Overview

Over the last decade, green investments have evolved from a niche investment strategy into one of the fastest-growing segments of the global financial system. Increasing awareness of climate change, food security, biodiversity conservation, and sustainable development has encouraged governments, institutional investors, and multinational corporations to allocate significant capital toward environmentally responsible sectors.

The agricultural sector has become a major beneficiary of this transition. Sustainable farming technologies, renewable energy, biological crop protection, precision agriculture, carbon farming, and digital agriculture are attracting increasing financial investments due to their ability to improve productivity while reducing environmental impacts.

Recent market reports indicate that the global sustainable agriculture market was valued at approximately USD 40.83 billion in 2025 and is projected to reach nearly USD 97.19 billion by 2034, growing at a compound annual growth rate (CAGR) of 10.19%. Europe currently represents the largest regional market, driven by strong sustainability regulations and investment incentives.

Similarly, the global ESG investing market reached approximately USD 39.08 trillion in 2025 and is expected to expand rapidly during the coming decade, reflecting the growing preference of investors for environmentally and socially responsible companies.

Why Investors Are Shifting Toward Green Agriculture

The investment landscape has changed considerably over the past decade. Earlier,

investors primarily focused on short-term financial returns. Today, long-term sustainability, climate resilience, and corporate responsibility have become equally important investment criteria.

Several factors are driving this transition:

- Rising global demand for sustainable food production.
- Climate change and increasing weather-related agricultural risks.
- Government incentives for green technologies.
- Expansion of ESG-based investment funds.
- Rapid growth of Agritech innovation.
- Increasing consumer demand for environmentally friendly food products.
- Carbon credit markets creating additional revenue opportunities.
- Stronger environmental regulations across developed and emerging economies.

These factors make sustainable agriculture an attractive sector for both institutional and retail investors.

Major Drivers of Green Agricultural Investments:

Driver	Impact on Agriculture	Investment Opportunity
Climate Change	Climate-resilient farming	High
ESG Investing	Sustainable business growth	Very High
Precision Agriculture	Higher productivity	High
Renewable Energy	Reduced production cost	High
Carbon Markets	Additional farm income	Additional farm income

Sustainable Agriculture and Stock Markets

Stock markets play a critical role in financing sustainable agricultural transformation. Publicly listed companies involved in agricultural biotechnology, irrigation technologies, biological crop protection, farm automation, renewable energy, and precision farming have attracted increasing investor attention over the last decade.

Investors are particularly interested in companies that:

- Develop climate-smart agricultural technologies.
- Manufacture biological fertilizers and biopesticides.
- Produce renewable energy solutions for agriculture.

- Build AI-based farm management platforms.
- Support carbon sequestration and regenerative farming.
- Improve agricultural supply chain sustainability.

Such companies often demonstrate higher innovation potential, stronger long-term growth prospects, and better ESG performance, making them attractive investment opportunities.

Emerging Investment Opportunities

Several emerging sectors are expected to drive future agricultural investment growth:

- Artificial Intelligence in Agriculture
- Agricultural Robotics
- Smart Irrigation Systems
- Carbon Farming
- Regenerative Agriculture
- Climate-Smart Crop Technologies
- Vertical Farming
- Biofertilizers and Bio stimulants
- Agricultural Biotechnology
- Digital Agricultural Platforms

These sectors are attracting venture capital, institutional investments, and stock market interest because they address both environmental challenges and long-term food security.

Environmental, Social, and Governance (ESG) Investing: The Foundation of Green Agricultural Finance

What is ESG Investing?

Environmental, Social, and Governance (ESG) investing is an investment approach that evaluates a company's long-term sustainability in addition to its financial performance. Instead of focusing solely on profits, ESG investors assess how responsibly a company manages environmental resources, supports society, and maintains ethical corporate governance.

In the agricultural sector, ESG investing encourages businesses to adopt sustainable farming practices, reduce environmental impacts, improve farmers' livelihoods, and maintain transparent governance. As global investors increasingly prioritize sustainability, ESG has become one of the most influential factors shaping agricultural investment decisions.



The Three Pillars of ESG

Environmental (E)

The environmental component evaluates how agricultural companies protect natural resources and reduce their environmental footprint.

Key indicators include:

- Reduction of greenhouse gas emissions
- Efficient water management
- Renewable energy adoption
- Soil conservation
- Biodiversity protection
- Waste reduction and recycling
- Sustainable fertilizer and pesticide management

Agricultural companies implementing these practices are generally viewed as lower-risk and more resilient investments.

Social (S)

The social dimension focuses on the impact of a company on employees, farmers, consumers,

and local communities.

Major indicators include:

- Fair wages and safe working conditions
- Farmer welfare and inclusion
- Gender equality
- Community development
- Food safety and quality
- Consumer health
- Employee training and skill development

Companies with strong social responsibility often build better stakeholder trust and long-term business stability.

Governance (G)

Governance evaluates how effectively a company is managed.

Important governance indicators include:

- Ethical business practices
- Transparent financial reporting
- Independent board oversight
- Risk management
- Regulatory compliance
- Anti-corruption policies
- Protection of shareholder interests

Strong governance improves investor confidence and supports sustainable long-term growth.

ESG Components in Sustainable Agriculture:

ESG Pillar	Agricultural Focus	Benefits
Environmental	Soil health, water conservation, renewable energy, carbon reduction	Climate resilience and resource efficiency
Social	Farmer welfare, labour safety, food security, community development	Improved social impact and stakeholder trust

Governance	Transparency, ethics, compliance, risk management	Strong investor confidence and sustainable growth

Why ESG Investing Matters in Agriculture

Agriculture is one of the sectors most affected by climate change and environmental degradation. At the same time, farming activities significantly influence natural ecosystems. ESG investing helps direct financial resources toward agricultural businesses that produce food responsibly while protecting the environment.

Companies with strong ESG performance often benefit from:

- Easier access to investment capital.
- Better operational efficiency.
- Lower regulatory and legal risks.
- Improved corporate reputation.
- Stronger long-term profitability.
- Greater resilience to climate-related challenges.

Consequently, ESG performance has become an important consideration for institutional investors, pension funds, and sustainable investment funds.

ESG Investing and Stock Market Performance

Over the past decade, investors have increasingly recognized that companies integrating ESG principles are often better positioned for long-term success. Sustainable agricultural businesses adopting climate-smart technologies, renewable energy, efficient resource management, and ethical governance generally attract greater investor confidence.

From a stock market perspective, ESG-focused companies may benefit from:

- Increased institutional investment.
- Improved access to green financing.
- Lower operational risks.
- Stronger brand value.
- Better long-term shareholder returns.

Although ESG adoption does not guarantee higher stock prices, it can enhance resilience and competitiveness over time, making these companies attractive to long-term investors.

ESG and Sustainable Agriculture: A Win–Win Strategy

The integration of ESG principles into agriculture creates value for multiple stakeholders:

- **Farmers** gain access to sustainable technologies and financial support.
- **Investors** benefit from long-term growth opportunities and reduced environmental risks.
- **Governments** advance climate and food security objectives.
- **Consumers** receive safer and more sustainably produced food.
- **The Environment** benefits from lower emissions, healthier soils, and improved biodiversity.

Thus, ESG investing serves as a bridge between financial growth and environmental sustainability, making it a cornerstone of modern green agricultural finance.

Key Takeaways

- ESG investing integrates environmental, social, and governance factors into investment decisions.
- Sustainable agriculture aligns closely with ESG principles.
- Strong ESG performance improves investor confidence and supports long-term business resilience.
- ESG-driven investments are accelerating innovation and sustainability across the agricultural sector.

Green Investment Opportunities in the Stock Market

The transition toward sustainable agriculture is creating significant opportunities in global stock markets. Companies that develop climate-smart technologies, renewable energy solutions, biological agricultural inputs, precision farming tools, and sustainable food systems are increasingly attracting long-term investors. These businesses are well positioned to benefit from the global shift toward low-carbon and environmentally responsible agriculture.

Why Sustainable Agriculture is Attractive to Stock Market Investors

Modern investors evaluate companies based not only on financial performance but also on their ability to address future environmental and social challenges. Agricultural companies adopting sustainable business models often demonstrate:

- Strong long-term growth potential.
- Lower environmental and regulatory risks.
- Higher operational efficiency.

- Increased innovation.
- Better access to ESG-focused investment funds.
- Stronger brand reputation among environmentally conscious consumers.

As a result, sustainable agriculture is becoming one of the fastest-growing investment themes within the global green economy.

Major Investment Areas in Sustainable Agriculture

1. Precision Agriculture

Companies developing GPS-guided machinery, AI-powered farm management software, drones, and IoT sensors help farmers optimize fertilizer use, irrigation, pest management, and crop monitoring.

Investment potential: Very High

2. Biological Agricultural Inputs

The demand for biofertilizers, biopesticides, and bio stimulants is increasing as governments and consumers seek alternatives to synthetic chemicals.

Investment potential: High

3. Renewable Energy for Agriculture

Solar-powered irrigation pumps, on-farm biogas plants, wind energy, and energy-efficient storage facilities reduce production costs and greenhouse gas emissions.

Investment potential: High

4. Carbon Farming

Farmers adopting conservation agriculture, agroforestry, and regenerative farming practices may earn additional income through carbon credit markets, creating new business opportunities for companies that measure, verify, and trade carbon credits.

Investment potential: Emerging and rapidly growing

5. Digital Agriculture

Cloud-based farm management platforms, blockchain-enabled supply chains, satellite monitoring, and AI decision-support systems improve farm efficiency and transparency.

Investment potential: Very High

Global Companies Driving Sustainable Agricultural Investments

Several internationally recognized companies are leading innovation in sustainable agriculture and continue to attract investor attention:

- Deere & Company – Precision agriculture equipment, autonomous machinery, and digital farming technologies.
- Trimble Inc. – GPS guidance systems and precision agriculture software.
- Corteva Agriscience – Sustainable crop protection, seed technologies, and biological products.
- Nutrient Ltd. – Precision nutrient management and sustainable fertilizer solutions.
- CNH Industrial – Smart agricultural machinery and automation.

These companies are investing heavily in research and development to improve productivity while reducing agriculture's environmental footprint.

Green Investment Opportunities in India

India is emerging as an important destination for sustainable agricultural investment due to its large farming sector, supportive government policies, expanding Agritech ecosystem, and increasing adoption of digital technologies.

Promising investment areas include:

- Precision farming technologies.
- Organic and natural farming enterprises.
- Biofertilizer and biopesticide manufacturers.
- Solar-powered irrigation systems.
- Climate-resilient seed technologies.
- Agricultural drone services.
- AI-based farm advisory platforms.
- Carbon farming and climate finance initiatives.

With increasing public and private investment, India's sustainable agriculture sector has strong potential for long-term growth.

Investment Risks

Despite significant opportunities, investors should also consider several risks:

- Climate variability and extreme weather events.
- Changes in environmental regulations.
- High initial investment costs.
- Technology adoption challenges among smallholder farmers.
- Market volatility.

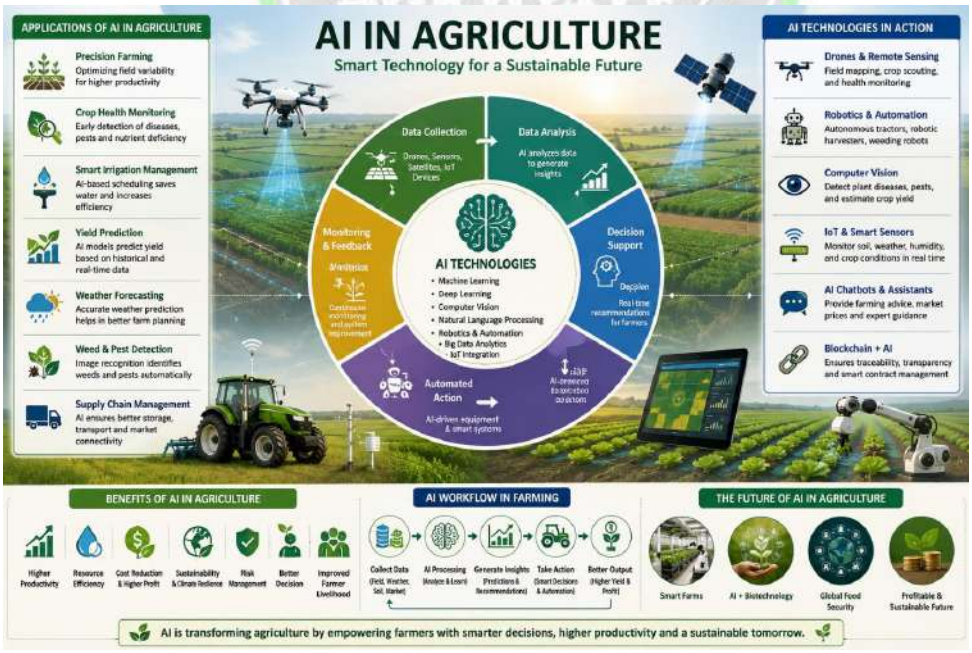
- Supply chain disruptions.

Proper diversification, scientific innovation, and supportive government policies can help reduce these risks.

Artificial Intelligence, IoT, Drones, and Digital Agriculture: The Technologies Powering Green Investments

Introduction

- The integration of advanced digital technologies into agriculture has created a new era of **smart and sustainable farming**. Traditional agricultural systems often depend on fixed input applications and manual decision-making, which can lead to inefficient use of resources. Digital agriculture addresses these challenges by using real-time data, automation, and intelligent decision-making systems to improve productivity while reducing environmental impacts.
- Technologies such as **Artificial Intelligence (AI), Internet of Things (IoT), drones, satellite imaging, robotics, blockchain, and big data analytics** are becoming important drivers of green investments. These technologies not only improve farm efficiency but also create attractive opportunities for investors by supporting innovative Agritech companies and sustainable business models.



Artificial Intelligence (AI) in Sustainable Agriculture

Artificial Intelligence has become one of the most transformative technologies in modern agriculture. AI systems analyze large volumes of agricultural data from weather stations, satellites, sensors, and farm records to provide accurate recommendations.

Major Applications of AI in Agriculture

1. Crop Monitoring and Yield Prediction

AI algorithms analyze satellite images and field data to predict crop growth, identify stress conditions, and estimate yields before harvesting.

Investment Opportunity:

AI-based agricultural platforms and analytics companies are attracting venture capital and institutional investments due to their potential to improve farm profitability.

2. Smart Pest and Disease Management

AI-powered image recognition systems can detect pest infestations and plant diseases at early stages. This enables targeted pesticide application, reducing chemical usage and environmental pollution.

Benefits:

- Reduced pesticide consumption
- Lower production costs
- Improved crop health
- Sustainable pest management

3. AI-Based Farm Advisory Systems

AI-driven digital assistants provide farmers with recommendations related to:

- Irrigation scheduling
- Fertilizer management
- Weather forecasting
- Crop selection
- Market information

These solutions improve decision-making and increase agricultural resilience.

Internet of Things (IoT) in Green Agriculture

The Internet of Things connects agricultural devices through sensors and communication networks to collect real-time information from farms.

Applications of IoT

Smart Irrigation Systems

Soil moisture sensors measure field conditions and automatically control irrigation systems according to crop requirements.

Advantages:

- Saves water
- Reduces energy consumption
- Improves water-use efficiency

Environmental Monitoring

IoT sensors monitor:

- Soil moisture
- Temperature
- Humidity
- Nutrient status
- Weather conditions

This enables precision management of agricultural resources.

Agricultural Drones and Remote Sensing

Drones and satellite-based technologies are revolutionizing farm monitoring by providing high-resolution field information.

Major Applications

- Crop health monitoring
- Nutrient deficiency detection
- Precision spraying
- Mapping of farm variability
- Disaster assessment

Drones help reduce input wastage by applying fertilizers and pesticides only where required, supporting sustainable farming practices.

Agricultural Robotics and Automation

Labour shortages and rising production costs have increased demand for agricultural robotics.

Modern agricultural robots are used for:

- Automated harvesting

- Weed removal
- Seeding operations
- Fruit picking
- Crop monitoring

Robotics companies are receiving increased investment because automation can improve efficiency while reducing dependence on labour-intensive practices.

Blockchain and Digital Supply Chains

Blockchain technology improves transparency and traceability throughout agricultural supply chains.

Applications:

- Farm-to-consumer traceability
- Food safety monitoring
- Certification of organic products
- Carbon credit verification
- Sustainable sourcing

Blockchain-based systems increase consumer trust and create new opportunities for sustainable food businesses.

Digital Technologies Driving Green Agricultural Investments:

Technology	Application	Sustainability Benefit
Artificial Intelligence	Yield prediction, disease detection	Efficient resource management
IoT Sensors	Smart irrigation, monitoring	Water and input conservation
Drones	Mapping and precision spraying	Reduced chemical usage
Robotics	Automation and harvesting	Improved productivity
Blockchain	Traceability and certification	Transparent supply chains

Investment Potential of Digital Agriculture

Digital agriculture represents one of the most promising areas for future green investments. The combination of agriculture and technology has created a rapidly expanding Agritech ecosystem

involving startups, multinational companies, research organizations, and financial institutions. Investors are increasingly interested in digital agriculture because these technologies:

- Improve farm productivity.
- Reduce environmental impact.
- Enable data-driven farming decisions.
- Create scalable business models.
- Support climate adaptation.

The future of agriculture will increasingly depend on the integration of biological innovation with digital intelligence, creating a new generation of sustainable agricultural enterprises.

Key Takeaways

- AI and digital technologies are transforming agriculture into a data-driven industry.
- Smart farming technologies improve sustainability while increasing profitability.
- Agritech companies are becoming important targets for green investment.
- Digital agriculture will play a central role in future food security and climate resilience.

Carbon Farming and Carbon Credit Markets: The New Economic Opportunity in Sustainable Agriculture

Introduction to Carbon Farming

- Carbon farming has emerged as one of the most innovative approaches linking climate action with agricultural economics. It refers to a set of agricultural practices that increase carbon sequestration in soils and vegetation while reducing greenhouse gas emissions from farming activities.



- Agricultural soils naturally store carbon in the form of organic matter. However, intensive tillage, excessive chemical inputs, deforestation, and poor land management have reduced soil carbon levels over time. Carbon farming aims to reverse this trend by improving soil health and transforming farms into carbon sinks.
- Unlike traditional farming systems that focus mainly on crop production, carbon farming creates an additional economic opportunity by allowing farmers and agricultural businesses to participate in carbon markets.

Major Carbon Farming Practices

Several sustainable agricultural practices contribute to carbon sequestration:

1. Conservation Agriculture

Conservation agriculture includes:

- Minimum or zero tillage
- Permanent soil cover
- Crop rotation

Benefits:

- Increases soil organic carbon
- Reduces soil erosion
- Improves soil structure
- Enhances water retention

2. Agroforestry

Agroforestry integrates trees with agricultural crops and livestock systems.

Benefits:

- Increased carbon storage
- Improved biodiversity
- Additional income from tree products
- Reduced climate vulnerability

3. Cover Cropping

Cover crops protect soil between main cropping seasons.

Advantages:

- Enhances soil fertility
- Prevents nutrient loss

- Increases organic matter
- Improves microbial activity

4. Biochar Application

Biochar is a carbon-rich material produced from agricultural residues through controlled heating.

Benefits:

- Long-term carbon storage
- Improved soil fertility
- Reduced greenhouse gas emissions
- Better crop productivity

5. Precision Nutrient Management

Optimized fertilizer application reduces unnecessary nitrogen emissions while maintaining crop productivity.

Technologies used:

- Soil sensors
- AI-based recommendations
- Variable rate technology

Understanding Carbon Credits

- A **carbon credit** represents one metric tonne of carbon dioxide equivalent (CO_2e) that has been reduced, removed, or avoided from the atmosphere.
- Carbon credits allow organizations that reduce emissions to generate financial value by selling these credits to companies seeking to offset their carbon footprint.
- In agriculture, farmers practicing carbon sequestration can potentially earn additional income by generating verified carbon credits.

Role of Companies and Investors in Carbon Agriculture

Carbon farming has attracted interest from:

- Climate technology companies
- Agri-finance organizations
- Carbon market platforms
- Agricultural technology startups
- Institutional investors

Investment opportunities are emerging in:

- Carbon measurement technologies
- Soil carbon monitoring
- Satellite-based verification systems
- Digital carbon platforms
- Climate-smart agriculture solutions

Companies providing carbon management services are becoming important players in the future green economy.

Carbon Farming Practices and Economic Benefits:

Practice	Environmental Benefit	Economic Opportunity
Conservation agriculture	Increased soil carbon	Carbon credit income
Agroforestry	Carbon storage and biodiversity	Timber and carbon revenue
Cover crops	Improved soil health	Sustainable farming incentives
Biochar	Long-term carbon sequestration	Biochar market opportunities
Precision farming	Reduced emissions	Lower input costs

Carbon Farming Opportunities in India

India has significant potential for carbon farming due to:

- Large agricultural land area
- Diverse farming systems
- Growing interest in climate-smart agriculture
- Increasing adoption of digital agriculture

Potential areas include:

- Rice methane reduction practices
- Agroforestry systems
- Natural farming
- Improved soil management

- Renewable energy integration in farms

Carbon farming can provide Indian farmers with additional income opportunities while supporting national climate goals.

Challenges in Carbon Markets

Although carbon farming has significant potential, several challenges remain:

1. Measurement Difficulties

Accurately measuring soil carbon changes requires advanced monitoring technologies.

2. Verification Costs

Certification and verification processes can be expensive for small farmers.

3. Market Uncertainty

Carbon credit prices may fluctuate depending on demand and regulations.

4. Farmer Awareness

Many farmers require training and technical support to participate effectively.

Future Outlook of Carbon Economy in Agriculture

Carbon farming is expected to become a major component of sustainable agriculture in the coming decades. Advances in:

- Artificial Intelligence
- Remote sensing
- Blockchain verification
- Soil monitoring technologies

will improve transparency and scalability of carbon markets.

As global industries move toward net-zero emission targets, agricultural carbon markets may become a significant source of investment, creating a strong connection between environmental sustainability and financial growth.

Government Policies and Global Initiatives Supporting Green Agricultural Investments

Introduction

Government policies play a crucial role in accelerating the transition toward sustainable agriculture by creating favourable conditions for investment, innovation, and technology adoption. Green investments require strong policy frameworks because sustainable agricultural technologies often involve high initial costs, long-term benefits, and coordination among farmers, industries, financial institutions, and researchers.

Around the world, governments are introducing climate policies, green finance mechanisms, carbon market regulations, and sustainable agriculture programs to encourage environmentally responsible farming systems. These initiatives are attracting private investments and creating new opportunities for agricultural companies and investors.

Global Initiatives Promoting Sustainable Agricultural Investments

United Nations Sustainable Development Goals (SDGs)

The United Nations Sustainable Development Goals provide a global framework for sustainable development.

Agriculture-related SDGs include:

SDG 2: Zero Hunger

Promotes sustainable food production, improved agricultural productivity, and food security.

SDG 12: Responsible Consumption and Production

Encourages efficient resource utilization and sustainable supply chains.

SDG 13: Climate Action

Supports climate-resilient agricultural practices and greenhouse gas reduction.

These goals have encouraged governments and investors to direct funds toward sustainable agriculture.

2. Paris Climate Agreement

The Paris Agreement aims to limit global temperature rise and encourages countries to reduce greenhouse gas emissions.

Agriculture contributes to climate action through:

- Carbon sequestration
- Reduced methane emissions
- Sustainable land management
- Renewable energy adoption

The agreement has increased investment interest in climate-smart agricultural technologies.

3. European Green Deal

The European Green Deal is one of the world's most ambitious sustainability strategies. It aims to make Europe climate-neutral by 2050.

Agriculture-related strategies include:

- Reduction of chemical pesticide dependency

- Promotion of organic farming
- Sustainable food systems
- Biodiversity conservation

These policies have increased demand for sustainable agricultural technologies and green investments.

4. United States Climate-Smart Agriculture Programs

The United States has increased support for climate-smart agriculture through funding programs that encourage:

- Soil carbon management
- Conservation practices
- Renewable energy adoption
- Sustainable livestock production

These initiatives create opportunities for farmers, AgriTech companies, and investors.

8.3 India's Policies Supporting Green Agricultural Investments

India is transitioning toward sustainable agriculture through several government initiatives focused on climate resilience, digital transformation, renewable energy, and resource conservation.

1. National Mission for Sustainable Agriculture (NMSA)

NMSA promotes:

- Climate-resilient farming
- Efficient water management
- Soil health improvement
- Sustainable agricultural practices

It supports farmers in adopting environmentally friendly technologies.

2. PM-KUSUM Scheme

The Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) promotes solar energy use in agriculture.

Benefits:

- Solar-powered irrigation pumps
- Reduced dependence on fossil fuels
- Lower energy costs

- Additional income opportunities

This scheme supports green energy investments in rural areas.

3. Digital Agriculture Mission

Digital Agriculture Mission focuses on developing:

- Digital farmer databases
- AI-based agricultural solutions
- Remote sensing applications
- Smart farming technologies

This creates opportunities for AgriTech startups and technology investors.

4. Paramparagat Krishi Vikas Yojana (PKVY)

PKVY promotes organic farming by supporting:

- Chemical-free agriculture
- Soil health improvement
- Sustainable production systems

It increases opportunities for organic food companies and biological input industries.

5. National Mission on Natural Farming

Natural farming initiatives encourage:

- Reduced chemical inputs
- Biological farming methods
- Soil biodiversity improvement
- Low-cost sustainable agriculture

This supports investment opportunities in biofertilizers, biopesticides, and sustainable food markets

Role of Governments in Attracting Green Investment

Governments support green agricultural investments through:

Financial Incentives

- Subsidies
- Grants
- Low-interest green loans

Research and Innovation Support

- Agricultural research funding

- Technology development programs
- Startup support

Market Development

- Carbon credit regulations
- Sustainable certification systems
- Green procurement policies

Infrastructure Development

- Digital connectivity
- Renewable energy infrastructure
- Cold chain and sustainable storage systems

8.5 Future Policy Direction

Future agricultural policies are expected to focus on:

- Carbon-neutral farming
- AI-based agricultural management
- Climate-resilient crops
- Circular bioeconomy
- Green financial instruments
- Sustainable food supply chains

Challenges and Risks Associated with Green Agricultural Investments:

1. High Initial Investment – Sustainable farming technologies require substantial upfront capital.
2. Climate Uncertainty – Extreme weather events can reduce agricultural productivity and investment returns.
3. Technology Adoption Barriers – Limited technical knowledge slows the adoption of advanced farming technologies.
4. Market Volatility – Fluctuations in agricultural commodity prices affect investment stability.
5. Carbon Credit Price Uncertainty – Changing carbon market prices may impact expected financial returns.
6. Regulatory Changes – Government policy and environmental regulation changes can influence investment decisions.

7. Limited Access to Green Finance – Smallholder farmers often face difficulties obtaining sustainable financing.
8. ESG Reporting Challenges – Lack of standardized ESG metrics makes company evaluation difficult.
9. Greenwashing Risk – Some companies exaggerate sustainability claims, reducing investor confidence.
10. Infrastructure Limitations – Poor digital connectivity and inadequate rural infrastructure hinder sustainable agriculture adoption.

Future Research Opportunities

Important research areas include:

- AI-based carbon measurement systems.
- Blockchain applications in agricultural finance.
- Sustainable investment models for small farmers.
- Biological solutions for climate-resilient agriculture.
- Integration of ESG metrics with agricultural performance.
- Digital platforms connecting farmers and investors.

Conclusion

Green investments are transforming sustainable agriculture into a dynamic and future-oriented investment sector. The integration of ESG principles, advanced technologies, renewable energy, and climate-smart farming practices is creating new opportunities for economic growth while addressing global environmental challenges. Although financial, technological, and policy-related risks remain, continued innovation and supportive government initiatives can accelerate the adoption of sustainable agriculture. Overall, green investments provide a strong pathway to achieving long-term food security, environmental sustainability, and attractive stock market opportunities for future investors.

References

Food and Agriculture Organization. (2023). *The State of Food and Agriculture 2023: Revealing the true cost of food to transform agrifood systems*. FAO.

Food and Agriculture Organization. (2024). *The State of Food and Agriculture 2024*. FAO.

United Nations Environment Programme. (2023). *Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions.*

World Bank. (2024). *Climate-Smart Agriculture and Sustainable Food Systems.*

OECD. (2023). *Agricultural Policy Monitoring and Evaluation.*

United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development.*

IPCC. (2023). *Climate Change 2023: Synthesis Report.*

Global Sustainable Investment Alliance. (2024). *Global Sustainable Investment Review*.

Principles for Responsible Investment. (2024). *ESG investment and sustainable finance trends.*

McKinsey & Company. (2023). *The future of agriculture and sustainable food systems.*

World Economic Forum. (2024). *Innovation in agriculture and food systems transformation.*

Klerkx, L., & Rose, D. (2024). Dealing with the game-changing technologies of agriculture. *Agricultural Systems.*

Zhang, Y., et al. (2024). Artificial intelligence applications in smart agriculture: Opportunities and challenges. *Computers and Electronics in Agriculture.*

Volume: 06 Issue No: 09

DIFFUSION AND ADOPTION OF INNOVATIONS: THE CASE OF THE KISAN DRONE SCHEME IN INDIA

Article ID: AG-V06-I09-30

Dr. J. Kavipriya[1*], Dr. M. Kavinila[2] and Dr. A. Vasuki[3]

1. Assistant Professor (Agr. Extension), School of Agriculture, Bharath Institute of Higher Education and Research, Selaiyur, Chennai, Tamil Nadu, India

2. Assistant Professor, Department of Agricultural Extension, Adhiyamaan College of Agriculture and Research, Athimugam, Shoolagiri, Krishnagiri, Tamil Nadu, India

3. Young Professional II, AICRP on WiA, Community Science College and Research Institute, TNAU, Madurai 625104, Tamil Nadu, India

*Corresponding Author: Dr. J. Kavipriya

Abstract

The Kisan Drone Scheme is a major technology initiative that uses unmanned aerial vehicles (UAVs) to modernize Indian agriculture. This chapter offers a thorough examination of the use of drones in Indian agriculture by combining official and scholarly sources with theoretical frameworks (Rogers' Diffusion of Innovations, TAM). Methodologically, we used phrases like "Kisan Drone" and "agricultural drone adoption" to undertake systematic searches of government websites (MoA/DAC, PIB) and scholarly databases (e.g., Scopus, Google Scholar). The program has the potential to increase productivity while lowering environmental effects by enabling data-driven decision-making, crop monitoring, and precision input application. However, because of institutional, technological, and socioeconomic limitations, the adoption and diffusion of this breakthrough differ greatly throughout locations. Using the theoretical framework of innovation diffusion, this chapter critically investigates the acceptance and spread of Kisan drones. It assesses policy frameworks, extension mechanisms, and service delivery models. Empirical examples from Tamil Nadu, Punjab, and Haryana show that drone spraying can enhance yields and reduce pesticide use, but adoption is still low (~3% of farmers as of 2024). In order to

promote fair adoption, the research emphasizes the significance of institutional support, group approaches, and adaptable strategies.

Keywords: Kisan Drone Scheme, Agricultural drones, Precision agriculture, Diffusion of Innovations, Technology Acceptance Model

Introduction

The desire to increase production, guarantee sustainability, and deal with new issues including climate variability, manpower shortages, and deteriorating soil health is driving a major shift in Indian agriculture. The industry nevertheless has structural limitations, such as dispersed landholdings, inefficient input usage, and restricted access to contemporary technologies, even though it provides a significant section of the people with their principal source of income. In this regard, using cutting-edge instruments like unmanned aerial vehicles (UAVs), also referred to as drones, has shown promise as a route toward resource efficiency and precision agriculture (Pathak & Brown, 2022). Drone technology supports the more general objectives of sustainable agricultural growth by facilitating data-driven decision-making, effective input application, and real-time monitoring.

The Government of India launched the Kisan Drone Scheme to encourage the use of drones in agricultural activities after seeing the revolutionary potential of this technology. The program is intended to make it easier for drones to be used for tasks including land surveys, fertilizer management, pesticide spraying, and crop health evaluation. The initiative seeks to make drone technology available to farmers, agri-entrepreneurs, and Farmer Producer Organizations (FPOs) through financial incentives, capacity-building programs, and institutional assistance. The program also demonstrates the government's dedication to raising farmers' incomes and upgrading agriculture through technical advancement (Government of India, 2022).

The Digital Agriculture Mission, which aims to create an agricultural ecosystem enhanced by technology, is part of the larger policy framework that the Kisan Drone Scheme functions within. The integration of cutting-edge technology like big data analytics, remote sensing, artificial intelligence, and geographic information systems into farming operations is a key component of this aim. Together, these programs seek to increase agriculture's resilience, efficiency, and transparency. It is anticipated that attaining long-term sustainability and food security will depend heavily on the integration of digital technologies with conventional farming methods (Food and Agriculture Organization, 2021).

However, widespread acceptance of new technology is not a given. A complex interaction of socioeconomic, cultural, institutional, and technological factors affects how innovations proliferate among farmers. The Diffusion of Innovations theoretical framework offers important insights into how and why farmers accept or reject new technology. This idea holds that adoption is a slow process with several steps, such as awareness, assessment, trial, and confirmation. Adoption decisions are heavily influenced by elements like perceived benefits, convenience of use, compatibility with current practices, and peer pressure (Rogers, 2003).

Drone technology adoption in India is still in its infancy, with significant regional and farming system variations. Smallholder farmers frequently encounter obstacles pertaining to cost, technical expertise, and accessibility, even if progressive farmers and institutional players have started to use drone-based solutions. Therefore, creating methods that effectively encourage the adoption of the Kisan Drone Scheme requires an understanding of its spread dynamics. By looking at institutional mechanisms, policy frameworks, and field-level experiences, this chapter seeks to assess how drone technology has spread and been used in Indian agriculture. Additionally, it emphasizes how service-based delivery models, group efforts, and extension programs can promote inclusive and long-lasting adoption.

Theoretical Frameworks

To analyze diffusion in this context, we draw on **Diffusion of Innovations (DOI)** and **Technology Acceptance Model (TAM)** frameworks. This hypothesis holds that adoption is a multi-stage process that starts with awareness and ends with continuous use rather than an immediate event.

When it comes to Kisan drones, the knowledge stage entails farmers learning about drone technology through peer networks, media exposure, or extension efforts. Farmers assess the perceived benefits and risks of drone use during the persuasion stage, which is defined by the construction of attitudes. The adoption or rejection of the technology is decided upon during the decision step. Drones are then incorporated into farming operations during the implementation stage. Lastly, depending on observed results, the confirmation stage validates the choice.

According to Rogers' DOI model, innovation spreads over time through adopter categories (innovators → early adopters → early/late majority → laggards) and is impacted by the characteristics of the innovation (relative advantage, compatibility with existing practices, complexity, trialability, and observability). Faster spraying and less chemical use are relative

advantages for Kisan Drones; complexity is related to the abilities needed. TAM (Davis, 1989) reduces individual acceptance to assessed utility and usability [25]. We modify TAM in rural India to incorporate elements mentioned in previous research, such as environmental and social impact, economic viability (affordability given modest budgets), and promotional activities (incentives, training) [27][26].

Therefore, our research will take into account how farmers view the value of drones (yield increases, cost savings [5][6]), how simple it is for them to locate them (technical support, complexity reduction via training [5][8]), and the impact of peers and extension (peer success stories, cooperative programs). At the system level, we also take into account the Diffusion Pathway: government policies and subsidies set off extension services (KVKs, CHCs), which in turn create a bandwagon effect by raising awareness and enabling early adopters to demonstrate benefits. Lastly, we highlight the organizational (FPOs, cooperatives) and environmental (regulatory, infrastructure) TOE elements that influence adoption preparedness. Our assessment of the Kisan Drone Scheme's development is guided by this comprehensive approach.

Methodology

We combined official and scholarly sources in a focused study of the literature. Using keywords like "Kisan Drone scheme," "agricultural drone adoption India," and "diffusion of innovation agriculture," academic publications were found using databases like Google Scholar and Scopus. Additionally, references within important papers were snowball sampled. Press Information Bureau releases, program instructions, and parliamentary records were among the official materials gathered from the Ministry of Agriculture and DAC websites. As primary sources, we quote PIB releases along with their reference IDs (PRID 2199566, for example). Relevance to drones or the spread of precision agriculture; (b) a clear technique or official status (government or peer-reviewed journal) were the inclusion criteria. Papers written in languages other than English or those were solely technical engineering (such as drone design) were disqualified, as were blog entries that lacked verifiable information.

Barriers and Drivers of Adoption

Our analysis identifies four categories of factors affecting drone adoption:

1. Economic Factors:

The most often mentioned obstacle is still high capital costs. According to surveys, almost 70% of farmers believe that costs are too high [4]. By paying up to half of the cost, the

Kisan Drone subsidies specifically target this. Consequently, economic viability increases: Drone spraying on maize lowered expenses by 22%, according to Ravikumar at al. [3], and Shankar et al. reported significant savings (30% cost reduction, 41% revenue gain) [6]. Farmers pay per-acre prices (often ₹200–300/acre as reported in case media), which are comparable to traditional spraying costs, in order to offset costs through service models. Adoption among eligible populations is thus substantially influenced by the scheme's financial assistance [1][28].

2. Social/Demographic Factors:

Diffusion is influenced by demographics. Younger, more educated farmers who are at ease with technology are typically early adopters [3]. On the other hand, unless they have assistance from custom hiring or cooperatives, smallholders and older farmers are slower. By educating women and enabling them to assist their communities, the Drone Didi program takes advantage of societal dynamics. Jaswinder Kaur from Punjab serves as an example of this; following training, she provided free demonstrations and gained the trust of the community, exhibiting the development of social acceptance [7][22]. A bandwagon effect is produced by peer influence (seeing successful adopters); researchers observe that farmers' propensity to adopt increases as they witness the advantages of their neighbors (Rogers' "observability"). We also observe social capital issues: information dissemination depends on training the average "idea-giver" farmer in each hamlet.

3. Technical Factors:

Drones require operational skills and maintenance. Without local support, technical issues (battery life, repairs) can be daunting. Studies highlight that *ease-of-use* improvements and training mitigate this barrier[5]. The Kisan Drone scheme addresses it partially by funding training in Krishi Vigyan Kendras and through partnerships with manufacturers. Advanced drone functionalities are limited in rural areas due to inconsistent connectivity (GPS signal, internet). But most basic drone spraying is done offline. Adoption is projected to accelerate as drone models become more robust and user-friendly, and as AI and autonomy advance (future directions mentioned by Singh & Singh [33]).

4. Regulatory Factors:

At first, DGCA rules (limited zones, pilot licenses) posed a significant obstacle, particularly for small farms. The government streamlined regulations for small UAVs and implemented a fast-track certification process for agricultural drones in 2021. One important

facilitator is this policy reform [23]. Bureaucratic hold-ups and the requirement for precise state-level regulations are current issues. However, regulatory liberalization is the general trend, supporting the momentum of adoption.

Factor	Drivers / Facilitators	Barriers / Challenges	Sources
Economic	Subsidies up to 75%; service models (CHCs) reduce cost; input savings (22–30%)[3][6]	High initial cost (70% cite expense); limited capital	[4][1]
Social	Peer success stories; outreach via KVKs & NGOs; Drone Didi empowering women[22][34]	Skepticism among traditional farmers; low literacy	[3][21]
Technical	Newer UAV models simpler; training programs; 5G/IoT integration	Skill gap; maintenance infrastructure; battery life	[5]
Regulatory	Revised Drone Rules (2021) easing licenses; government fast-track approvals	Previous strict DGCA approvals; lack of local policies	[23]

Table 1. Summary of major drivers and barriers to drone adoption in Indian agriculture (with representative citations). Drivers include subsidies and awareness programs; barriers include cost and technical challenges.

Policy Implications

Our findings have several implications for policy and practice

- **Strengthen Financial Mechanisms:**

  The effectiveness of subsidies in lowering cost barriers suggests that ongoing financial assistance is essential. To pay for running costs (batteries, training), think about increasing caps or expanding subsidies. Capital limitations may be further alleviated by low-interest loans or credit guarantee programs aimed to drone service entrepreneurs.

- **Grow the Custom Hiring Network:**

  Promote additional CHCs and drone service providers. Permissions for CHC formation could be expedited by state and municipal governments. Smallholders will have access to drones without having to buy them if CHCs are connected to villages via extension networks.

- **Increase Training and Extension:**

Increasing training programs—especially those aimed at women and young people—is essential because a known obstacle is a lack of skill. Drone technology courses should be supported by KVKs, vocational schools, and private training partners.Success stories from model farmers (as seen in Punjab) should be documented and publicized to build trust.

- **Track and Assess Impact:**

Conduct data gathering on drone use and results. Extension reports should be used to monitor metrics like as yield changes, input reductions, and hectares serviced. This data can support ongoing investment and guide iterative policy changes.

- **Regulatory Support:**

Keep simplifying regulations. Simplify authorization procedures and take into account local regulations (such as altitude and safe zones). To allay outmoded concerns, make sure farmers are informed clearly about the eased regulations.

- **Public-Private Collaboration:**

Encourage collaborations between the government, startups, and cooperatives like IFFCO. Uptake can be accelerated, for example, by agri-tech businesses leasing advanced drones at a discount or co-financing demonstration projects.

- **Inclusive Targeting:**

Make sure marginalized and isolated communities are taken into account. Geographic gaps can be avoided by using mobile demo units and regional pilots in tribal or rainfed areas.The focus on women (Drone Didi) is well-placed; similar inclusive approaches (e.g. training for smallholders) should continue.

These policy directions are supported by the literature. For example, Singh & Singh (2025) recommend government-led incentives and service-based models. Similarly, the successful Drone Didi case suggests targeted programs can have broad positive spillovers

Conclusion

The Kisan Drone Scheme represents a major policy experiment in technology diffusion within Indian agriculture. By combining substantial subsidies with targeted outreach (e.g. Drone Didi), the government has effectively lowered entry barriers and stimulated the initial "take-off" of drone services. However, adoption is still low, which reflects ongoing issues with knowledge, capability, and cost. There is broad agreement in the examined literature regarding the

advantages of drones (more safety, lower input costs, and enhanced efficiency), indicating that diffusion has great potential if ongoing support is given.

Based on empirical data and diffusion theory, our study concludes that Kisan Drones' success will depend on expanding its diverse strategy and combining innovation traits (advantage, trialability, etc.) with social system preparedness. This includes infrastructure, community involvement, education, and financial incentives. The Kisan Drone Scheme may serve as a model for scaling other agri-innovations if policymakers take note of these lessons, such as by monitoring results and making iterative program adjustments.

In conclusion, the Kisan Drone instance shows that technology adoption is a process impacted by the interaction of economics, culture, and policy in a complex agricultural sector. The significance of evidence-based policy and ongoing stakeholder feedback is emphasized in our chapter. We recognize that some information (such as precise adoption rates and long-term environmental effects) is still unknown and urge more study. However, the present trend indicates that drones are progressively becoming a common farming equipment in India, with the Kisan Drone Scheme acting as a major driver.

Volume: 06 Issue No: 09

VIRUDHUNAGAR SAMBA CHILLI: TRADITIONAL CULTIVATION WITH MODERN PRACTICE

Article ID: AG-V06-I09-31

B. Deepika*[1], B. Venudevan[2], K. Sujatha[2], T. Sasidharan[2] and V. Alex albert[2]

[1] Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore - 641 003, Tamil Nadu, India.

[2] Department of Seed Science and Technology, Agricultural College and Research Institute, Madurai - 625 104, Tamil Nadu, India.

*Corresponding Author: B. Deepika

Abstract

Chilies is one of the most important spice crops grown across India, adding taste, colour and value to daily food and to the country's export basket. Among the many chilli varieties cultivated in India, Virudhunagar district in Tamil Nadu is famous for producing the popular Samba chilly, known for its unique flavour, moderate heat, vibrant red colour and excellent keeping quality. This region's unique soil type, warm climate and traditional farming practices make it especially suitable for chilly cultivation and Samba chilli has become a major source of income for thousands of small and marginal farmers in the area.

Keywords: Virudhunagar samba chilli, Chilli cultivation, Irrigation, Pest management, Harvesting and Seed Storage.

Introduction

It is one of the most important horticultural crops in the world. It is grown in many parts of the country and plays a major role in Indian agriculture, trade and everyday cooking. Farmers across states like Andhra Pradesh, Karnataka and Tamil Nadu depend on chilli farming for their income. Tamil Nadu makes a strong contribution to India's chilli production. Among the different chilli-growing regions in the state, Virudhunagar district is especially well known. The chilli grown here, called Virudhunagar Samba chilli, is considered unique and highly valued.

Chilli makes special in its high pungency (spiciness), bright red colour, and strong aroma. Because of these qualities, earned it a Geographical Indication (GI) tag, by the GI Registry, Government of India, following an application by the Tamil Nadu State Agricultural Marketing Board together with the Virudhunagar Chilies Merchants Association and protects its identity and boosts its reputation in both domestic and international markets. This recognition adds value to the crop and creates better opportunities for farmers who cultivate it

This chilli variety is also very important for the farmers who grow it. For many families in Virudhunagar, chilli farming is their main source of income, helping them meet daily needs, support their children's education and improve their standard of living.

Climate and Soil

Chilli thrives in warm conditions and needs dry, clear weather while the fruits are maturing and drying. A temperature range of 20–25°C is considered ideal for good growth, while temperatures above 37°C combined with low humidity at flowering can cause flower and young fruit drop. In the Virudhunagar belt, the relatively dry climate with well-distributed sunshine hours is considered one of the reasons the local Samba chilli develops its characteristic colour, aroma and pungency.

The crop can be grown under rainfed conditions where annual rainfall is between 850 and 1,200 mm. Chilli adapts to a wide range of soils, but performs best in well-drained sandy loam to red loamy soils with good moisture-holding capacity, waterlogged or poorly drained soils encourage root and collar rot. A soil pH of about 6.0 to 7.5 is considered optimum and fields with a history of solanaceous crops.

Nursery Management

Good nursery management lays the foundation for a healthy stand in the main field. About 400–500 g of seed is generally sufficient to raise seedlings for one acre of transplanted crop. Choose a well-drained, fertile piece of land that has access to irrigation. Prepare raised nursery beds of about 3m length, 1m width and 15cm height. Leave 30cm pathways between beds for easy drainage and access. Mix in well-rotted farmyard manure at 2-3 kg per sq.m, along with a small amount of neem cake. The neem cake helps to keep soil pests away and improves soil health. Before sowing, treat the seeds with Trichoderma viride @ 4g per kg of seed or with carbendazim / Captan @ 2-3g per kg. This protects young seedlings from damping-off disease. Sown the treated seeds in shallow lines kept 5cm apart. Cover them lightly with sand or fine soil

and then mulch the bed with dry straw. Water immediately using a rose can with fine spray. Seeds usually germinate in 8-10 days. About 20-25 days after sowing give a light foliar spray of 1% urea. This helps to improve seedling vigor and makes them strong for transplanting.

Main Field Preparation

Start with deep ploughing 2-3 times to bring the soil to a fine tilth. After that, do harrowing to break the clods and make the soil loose. During the last ploughing, apply well-decomposed FYM or compost at 10-12 tonnes per acre and mix it well into the soil. Level the field properly so that irrigation and drainage are uniform. This is very important because chilli is very sensitive to waterlogging.

Before forming beds, apply the basal dose of NPK fertilizer. A common recommendation is 20:20:20 kg per acre of N, P and K. Also add neem cake at 100-150 kg per acre which improves soil health and helps to control nematodes and other soil pests. Form ridges and furrows or raised beds based on your irrigation method. For ridges and furrows, keep 60-75cm spacing between rows. If you are using drip on a flatbed, you can maintain similar row spacing. Make proper drainage channels around the field, especially if your area gets heavy rains. The standard spacing for transplanting Samba chilli is 60cm x 45cm or 75cm x 45cm. Choose the spacing based on soil fertility and plant growth.

Nutrient Management

Chilli needs a lot of nutrients because it grows for a long duration. For irrigated chilli in Tamil Nadu, a general dose is 60-75 kg Nitrogen, 40-50 kg Phosphorus, and 40-50 kg Potash per acre. Phosphorus and Potash - Apply the full dose as basal at the time of transplanting. Nitrogen- Split it into 2-3 doses. Give the first dose as basal, then at 30 days and 60 days after transplanting. This matches with plant growth and flowering. Don’t give all nitrogen at once or the plant will grow only leaves and give less fruit.

Micronutrients

Deficiency of Zinc, Boron and Calcium is common. It causes poor fruit set, flower drop, blossom-end rot and small deformed fruits. To fix this, take a micronutrient mixture @ 2.5-3g per litre of water and spray it. Give the first spray at 30-40 days after transplanting, second at flowering and third at early fruiting. A calcium nitrate spray during flowering also helps to reduce flower drop and gives better fruit setting.

Water Management

Chilli is very sensitive to water management. It does not grow well in waterlogged soil and both too little and too much water can reduce flowering and fruit setting. Therefore, irrigation should be given carefully. Under flood or furrow irrigation, watering once every 7–10 days is usually enough. During hot and dry weather and especially at the flowering and fruit development stages, irrigation should be given more frequently about once every 5–6 days.

Drip irrigation is a better option for Samba chilli cultivation because it supplies water directly to the plant roots. It saves about 30–40% more water than flood irrigation and keeps the leaves drier, which helps reduce fungal diseases. Drip irrigation also makes it easy to apply fertilizers along with irrigation water in small, regular amounts, improving nutrient use by the crop. When drip irrigation is used together with mulching, it helps control weeds, conserve soil moisture and produce fruits with more uniform colour and size, which are important quality traits for the GI-tagged Samba chilli.

Weed Management

Weeds compete strongly with chilli in the first 45–60 days after transplanting, before the canopy closes, and can significantly depress yield if left unchecked. Two manual weedings, the first at around 20–25 days after transplanting and the second about three weeks later, are generally sufficient under good field conditions, combined with light earthing-up to support the plants and improve drainage around the root zone.

Pest and Disease Management

Pest and disease	Symptoms	Management
Thrips	Upward curling and crinkling of leaves; silvery streaks on the leaf surface; stunted growth	Planting agathi (*sesbania grandiflora)* around the field provides partial shade and helps to control Thrips population. Yellow sticky trap @12/acre.
Aphid	Downward curling of leaves, sooty mould, and sticky honeydew deposits.	Planting a trap crop like maize and sorghum. Neem seed kernel extract 5%; release of Chrysoperla; avoid water stress.
Fruit borer	Circular bore holes on fruits; larvae feeding inside; premature fruit drop.	Planting a trap crop Marigold; Pheromone traps @ 5/acre; hand-picking; Spray NSKE 5% (or) ginger-garlic-chilli kashtam.
Damping-off (nursery)	Rotting of seedlings at the collar region; sudden toppling of young plants	Seed treatment with *Trichoderma viride* @ 4 g/kg; drenching nursery beds with copper oxychloride
Anthracnose (Die back)	Sunken, dark, water-soaked spots on fruits; drying of twigs from the tip downward.	Spray copper oxychloride or a recommended fungicide; remove and destroy affected plant parts
Leaf curl (viral)	Puckering and curling of leaves, stunted bushy plants, and poor fruit set.	Rogue out infected plants early; control whitefly/thrips vectors; use tolerant lines.

CHILLI ANTHRACNOSE



CHILLI APHID



Harvesting

For the dried, GI-registered Samba Vathal product, fruits are allowed to ripen fully on the plant to a deep red colour before picking, since immature or partially ripe fruits dry to a poorer colour and lower pungency. The Harvesting season in virudhunagar and sattur region typically from February to May. Harvesting typically begins about 90 days after transplanting and continues over 5–8 pickings at intervals of 10–15 days as fruits mature in flushes.





After picking, fruits are heaped for a day to even out colour before being spread in thin layers on clean drying yards or raised platforms and sun-dried for 10–15 days, with regular turning to ensure uniform drying and to prevent mould. Fruits should be dried to a moisture content of about 8–10% for safe storage, well-dried, properly graded pods are then packed in clean gunny bags and stored in a cool, dry place away from direct sunlight and pest access, since the wrinkled texture and deep colour that define Samba Vathal in the market depend on careful post-harvest handling.

Yield and Economics

A successful crop yield between (7.5 – 10 quintals) or (2-3 tonnes / ha) dry pods per acre. Samba chilli has a GI tag, it gets a higher price than normal dry chilli in Virudhunagar, Sattur and Thoothukudi markets.

Future Perspective

Virudhunagar Samba Chilli has got a GI Tag from the Government of India. The application was given by the Tamil Nadu State Agricultural Marketing Board and Virudhunagar Chillies Merchants Association. This will help farmers get better prices and recognition. A new plan focuses on protecting seed purity, promoting sustainable farming, increasing yield and bringing back Virudhunagar as a top chilli export hub.

The chilli is already exported to Sri Lanka and other countries.

Conclusion

Virudhunagar Samba Chilli is a special and valuable crop grown in the Virudhunagar district of Tamil Nadu. It is famous for its bright red color, medium spice level and good quality, which makes it popular in both local and export markets. With proper soil preparation, timely irrigation, correct use of fertilizers and good pest and disease control that farmers can get a healthy yield and better income from this crop. It also gives virudhunagar farmers a unique identity, since the chilly has a Geographical Indication (GI) tag that protects its name and quality. If farmers continue to use good farming practices, modern techniques and proper marketing support, Samba Chilly cultivation for helping both farmers and the local economy grow.

Volume: 06 Issue No: 09

RAINY-SEASON LIVESTOCK MANAGEMENT: PRACTICAL MEASURES FOR HEALTHY ANIMALS AND BETTER FARM PRODUCTIVITY

Article ID: AG-VO6-I09-32

Mayank Dubey

College of Veterinary & Animal Sciences, Banda University of Agriculture & Technology Banda (UP) 210001 India

Introduction

The rainy season brings much-needed water, green vegetation and opportunities to reduce feeding costs, but it also creates a challenging environment for livestock and poultry. High humidity, fluctuating temperatures, stagnant water, muddy surroundings and increased parasite activity can together create conditions in which infectious and parasitic diseases spread more easily. For livestock keepers, prevention therefore becomes far more economical and practical than waiting for disease to appear.

During the monsoon, special attention should be given to vaccination, housing, hygiene, feed and fodder management, parasite control, drinking water, and early identification of sick animals. Dairy animals, goats and poultry have different requirements, but the basic principle is the same: keep the animals dry, clean, adequately nourished and protected from contaminated surroundings. A well-managed shed and a simple preventive health programme can substantially reduce avoidable losses and help animals maintain production.

Why the Monsoon Requires Extra Care

Rainfall increases moisture in animal shelters, feeding areas and surrounding fields. Wet floors and poorly drained sites remain damp for long periods and become favourable environments for many disease-causing organisms. External parasites such as flies, ticks and lice may also become more troublesome. At the same time, internal parasites, including worms, may increase and affect the health and performance of grazing animals.

Humidity and temperature fluctuations can also affect feed intake, digestion and the general disease resistance of animals. When animals remain in wet or poorly ventilated shelters,

skin problems and fungal infections may occur. In dairy animals, prolonged exposure to wet and dirty surfaces increases the risk of udder-related infections, making hygienic housing particularly important.

The economic effect of these problems is often greater than the cost of prevention. Disease may reduce milk, meat or egg production, slow growth, increase veterinary expenses and, in severe cases, cause mortality. Preventive management should therefore be treated as an essential part of monsoon farm planning rather than as an emergency response.

1. Vaccination and Preventive Health Care

Vaccination should be planned before the rainy season wherever the recommended schedule calls for it. The source article specifically highlights diseases such as foot-and-mouth disease, haemorrhagic septicemia, black quarter, lumpy skin disease and chickenpox among the infections that require attention in livestock during periods of increased disease risk. Farmers who have not completed vaccination of their animals should contact the local veterinary or animal husbandry department and follow the locally recommended vaccination schedule.

Vaccination is only one part of preventive health care. Farmers should observe animals every day for changes in appetite, activity, body temperature, milk yield, stool consistency, coughing, nasal discharge, skin lesions, lameness or abnormal behaviour. Any animal showing signs of illness should be separated from healthy animals and examined by a qualified veterinarian.

Preventive treatment against internal parasites should also be planned according to veterinary advice and the local parasite situation. The source material recommends special attention to deworming during the rainy season because internal parasites can increase substantially. Rather than giving medicines indiscriminately, farmers should follow veterinary guidance regarding the appropriate drug, dose, timing and withdrawal requirements.

2. Housing: Keep Animals Dry, Clean and Well Ventilated

The animal shed is the first line of defence during the monsoon. Roofs should be inspected before heavy rainfall and repaired so that water does not leak into the resting or feeding area. Floors should be sloped sufficiently for drainage, and standing water should not be allowed to accumulate around the shed.

Animals should preferably be kept in elevated, dry, shaded and well-ventilated places. Newly born and lactating animals deserve particular attention because wet and uncomfortable

conditions can adversely affect their health and performance. Clean and dry bedding should be provided where bedding is used, and wet material should be removed promptly.

Ventilation is equally important. A closed shed may remain humid even when rain is not falling, encouraging fungal growth and unpleasant odours. Adequate air movement helps reduce moisture and improves the comfort of animals. However, ventilation should not mean exposing animals to direct cold drafts or rain.

The area surrounding the shed should also be kept free from weeds, excessive vegetation, dung accumulation and stagnant water. Good drainage reduces breeding sites for flies and other pests and makes routine cleaning easier.

3. Feed and Fodder Management During the Rainy Season

The monsoon offers an opportunity to improve the availability of green fodder. Farmers can establish or utilize fodder crops such as maize, bajra, MP chari, sorghum, Napier grass and other locally suitable fodder crops. A reliable supply of green fodder can strengthen the feeding programme and reduce expenditure on purchased feed.

However, abundant green fodder should not automatically replace all dry roughage. Sudden changes in diet and excessive dependence on very succulent green fodder can disturb digestion. The source material therefore recommends mixing green fodder with dry hay or straw during the rainy season. A balanced ration should be maintained according to the animal's species, age, physiological status and production level.

Feed storage is particularly important during humid weather. Grain, concentrate mixtures, hay and other feed materials should be stored above ground in a clean, dry and well-ventilated store. Water leakage and dampness can encourage mould and fungal growth and may result in unsafe feed. Farmers should inspect stored feed regularly and discard visibly spoiled or mouldy material rather than feeding it to animals.

Feeders and water troughs should also be cleaned regularly. Leftover wet feed should not be allowed to remain in the manger for long periods, because it can ferment or spoil rapidly under humid conditions.

4. Management of External and Internal Parasites

Rainy conditions often favour the multiplication and persistence of external parasites such as flies, ticks and lice. These parasites irritate animals, interfere with comfort and may

contribute to the spread of infections. Regular cleaning of the shed, removal of manure and control of weeds around animal housing are basic measures that can reduce parasite pressure.

Where chemical control is necessary, insecticides or other ectoparasite-control products should be used strictly according to veterinary or product-label instructions. The treatment should be applied at appropriate intervals and with attention to animal safety, environmental safety and any relevant milk or meat withdrawal requirements.

Internal parasites are also an important concern, especially in grazing animals. Worm burdens can reduce appetite, growth and feed utilization and may become particularly important during and after periods of rainfall. Deworming should therefore form part of a planned health programme. The appropriate interval and medicine should be decided with veterinary advice rather than by routine, repeated use of the same product.

5. Special Care of Dairy Animals

Dairy animals require additional attention because disease and nutritional stress can directly reduce milk production and reproductive performance. During the rainy season, dairy cows and buffaloes should be kept in dry resting areas, and particular care should be taken with the cleanliness of the floor around the animals.

Milking hygiene should be maintained carefully. The udder and teats should be kept clean and dry, and milking equipment should be washed and maintained properly. Wet and contaminated floors increase the opportunity for disease-causing organisms to come into contact with the udder. Early detection of abnormal milk, swelling, heat or pain in the udder can help in timely veterinary intervention.

Lactating animals should receive sufficient nutrients rather than being allowed to depend exclusively on pasture or green fodder. Green fodder should be combined with appropriate dry fodder and concentrate according to production needs. Adequate clean drinking water should remain available throughout the day.

Newborn calves require special protection from wet and dirty surroundings. They should be provided with a clean, dry and sheltered resting area. Young animals are particularly vulnerable to environmental stress and infections, so hygiene and timely veterinary care are essential.

6. Special Monsoon Management for Goat Keepers

Goats are often considered hardy animals, but prolonged exposure to wet conditions can create significant health problems. Goat housing should therefore be designed to keep animals' above damp ground. A raised platform made from suitable wood or bamboo can help provide a dry resting surface, particularly in areas where rainwater accumulates.

Goats should be housed in a clean, dry and properly ventilated enclosure. The pen should be cleaned regularly, and wet or contaminated bedding should be removed. Good sanitation reduces the risk of infections and helps control parasite multiplication.

The source material emphasizes deworming at intervals of approximately three to four months and vaccination against important diseases such as PPR and enterotoxaemia. These measures should be integrated with the local veterinary vaccination and parasite-control programme.

Grazing management also needs adjustment during rainfall. Goats should not be allowed to consume obviously wet, spoiled or contaminated fodder. The source material recommends taking goats for grazing after the sun has been out for some time and returning them while the conditions remain suitable. In addition to grazing, a regular supply of grain and dry fodder or straw helps maintain growth and body condition during the rainy season. The source recommends approximately 100–150 g of concentrate and 1.5–2 kg of dry fodder/straw per goat, while recognizing that actual requirements vary with body size, age, production and pregnancy status.

7. Special Monsoon Management for Poultry

Poultry sheds are highly sensitive to humidity. Excess moisture in litter can increase microbial growth, produce unpleasant gases and favour the spread of infectious diseases. The poultry house should therefore be kept dry, well ventilated and protected from rainwater entry.

Farmers should prevent birds from drinking contaminated or stagnant water. Clean drinking water should be supplied regularly, and drinkers should be washed to prevent contamination. The source material highlights the risk of internal parasites from dirty water and recommends appropriate preventive treatment during the rainy season under veterinary guidance. For laying hens, maintaining a suitable environment is important for sustaining egg production. The source material specifically mentions the use of heaters and bulbs during this season where

required. Such equipment should be used safely and according to the birds' environmental requirements, avoiding excessive heat and fire hazards.

Poultry may also require adequate feed because environmental stress can increase nutritional demands. A balanced, nutrient-dense ration should be provided rather than relying on insufficient or poor-quality feed. Vaccination should be maintained according to the recommended poultry health schedule, particularly against diseases prevalent in the local production system.

8. Drinking Water and Grazing Safety

Water is essential, but during the rainy season its quality becomes a major management issue. Ponds, pits, ditches and other low-lying places may contain contaminated water after rainfall. Animals should not be allowed to drink from visibly polluted or stagnant sources.

Before animals are sent outside for grazing, they should have access to clean drinking water. This can reduce the likelihood of animals drinking contaminated water from ponds or water-filled depressions. Clean water troughs should be washed regularly, and water should be replaced when it becomes dirty.

Grazing areas should also be inspected for flooding, excessive mud, sharp objects, spoiled vegetation and other hazards. Farmers should avoid keeping animals for prolonged periods in waterlogged fields. A safe grazing routine protects both animal health and productivity.

9. Isolation and Early Treatment of Sick Animals

One sick animal can become a source of infection for others, especially when animals are housed closely together. Any animal showing clear signs of infectious disease should therefore be separated promptly from the healthy group. The affected animal should be examined and treated by a qualified veterinarian.

Isolation should be accompanied by cleaning and disinfection of the affected area and careful disposal or handling of contaminated materials. Farmers should avoid moving sick animals unnecessarily between farms, markets or common grazing areas.

Early reporting is particularly important for diseases that may spread rapidly. Farmers should contact veterinary personnel when they observe unusual numbers of sick animals, sudden deaths, fever, severe diarrhoea, respiratory signs, lameness, skin lesions or sudden reductions in milk or egg production.

10. A Simple Monsoon Action Plan for Farmers

A practical monsoon plan can be organized into a few simple steps. First, inspect the roof, floor, drainage and ventilation of every livestock and poultry shed before heavy rains begin. Second, review vaccination and deworming records and contact the veterinary department for any pending preventive measures. Third, arrange sufficient green and dry fodder and shift feed storage to a dry location. Fourth, establish a routine for cleaning manure, controlling flies and ticks and removing stagnant water. Fifth, monitor animals daily and isolate sick individuals immediately.

Farmers should give additional attention to pregnant animals, lactating animals, newborns, young goats and laying poultry. These groups may require more careful nutrition, shelter and health monitoring. Keeping basic records of vaccination, deworming, illness, milk production, egg production and mortality can also help identify recurring problems and improve future farm planning.

Conclusion

The rainy season should be viewed not only as a period of disease risk but also as an opportunity to strengthen livestock management. The availability of green fodder can support feeding programmes and reduce costs, while timely preventive health care can protect animals from avoidable disease and production losses.

The most effective strategy is preventive: vaccinate according to the recommended schedule, maintain clean and dry housing, control parasites, protect feed from moisture and mould, provide safe drinking water, balance green fodder with dry roughage, and seek veterinary attention promptly when illness appears. Dairy animals, goats and poultry each require some specific measures, but all benefit from the same foundation of hygiene, nutrition, shelter and observation.

For livestock farmers, monsoon management is ultimately an investment in productivity. A few hours spent preparing sheds, fodder stores, drainage and health schedules before and during the rainy season can prevent much larger economic losses later. Healthy animals are more productive animals, and careful seasonal management is one of the simplest ways to protect farm income and animal welfare.

Volume: 06 Issue No: 09

GENOMIC SURVEILLANCE OF ANTIMICROBIAL RESISTANCE

Article ID: AG-V06-I09-33

Geetharani P

Department of Aquatic Animal Health Management, Faculty of Fisheries Science, Kerala University of Fisheries and Ocean Studies (KUFOS), Panangad, Kerala, India

Abstract

Antimicrobial resistance (AMR) is one of the most significant threats to global public health, food security, and sustainable aquaculture. Excessive and inappropriate use of antibiotics in aquaculture has accelerated the emergence of resistant bacteria, reducing treatment efficacy and increasing disease outbreaks. Conventional surveillance methods often fail to detect emerging resistance genes before they spread widely. Recent advances in genomic technologies, including Whole Genome Sequencing (WGS), Next-Generation Sequencing (NGS), metagenomics, and bioinformatics, have transformed AMR surveillance by enabling rapid detection and characterization of antimicrobial resistance genes and resistant bacterial strains. Genomic surveillance facilitates early outbreak detection, tracks the evolution and transmission of resistant pathogens, and supports evidence-based antibiotic stewardship. It also strengthens the One Health approach by integrating animal, environmental, and human health surveillance. Emerging technologies such as portable sequencing platforms and artificial intelligence are expected to further improve real-time monitoring of antimicrobial resistance in aquaculture. Continued investment in genomic surveillance will play a vital role in protecting aquatic animal health and promoting sustainable aquaculture production (WHO, 2023; FAO, 2024; WOAH, 2023).

Keywords: Antimicrobial resistance, Genomic surveillance, Whole genome sequencing, Next-generation sequencing, Aquaculture, Resistome, One Health, Antibiotic stewardship.

Introduction

Aquaculture is one of the fastest-growing food production sectors and plays a crucial role in global food security. However, bacterial diseases remain a major constraint to sustainable

production, often leading to significant economic losses. Antibiotics are widely used to control these infections, but their excessive and indiscriminate use has accelerated the development of antimicrobial-resistant bacteria in aquatic environments (FAO, 2024).

Antimicrobial resistance occurs when microorganisms acquire the ability to survive exposure to drugs that were previously effective against them. Resistant bacteria can spread through water, sediments, aquatic animals, and humans, making AMR a serious **One Health** concern. The World Health Organization has identified AMR as one of the top global public health threats because it compromises the treatment of infectious diseases in both humans and animals (WHO, 2023).

Traditional surveillance relies on bacterial isolation and antimicrobial susceptibility testing, which provide limited information about resistance mechanisms and pathogen evolution. Advances in genomic technologies have revolutionized AMR surveillance by enabling comprehensive analysis of bacterial genomes and resistance genes. Genomic surveillance combines high-throughput sequencing with bioinformatics to monitor resistant pathogens, identify emerging resistance genes, trace transmission pathways, and support evidence-based disease management in aquaculture (Ellington et al., 2017; Hendriksen et al., 2019).

What is Genomic Surveillance?

Genomic surveillance is the continuous monitoring of microorganisms through analysis of their genetic material using advanced sequencing technologies. Unlike conventional diagnostic methods that examine only bacterial growth or antibiotic susceptibility, genomic surveillance investigates the entire genome, providing detailed information on antimicrobial resistance genes, virulence factors, mobile genetic elements, and evolutionary relationships (Didelot et al., 2012).

Modern genomic surveillance employs technologies such as Whole Genome Sequencing (WGS), Next-Generation Sequencing (NGS), metagenomics, and bioinformatics to analyse thousands of microbial genomes simultaneously. These approaches enable rapid identification of resistant bacteria, detection of emerging resistance genes, and monitoring of pathogen evolution before major disease outbreaks occur (Hendriksen et al., 2019).

In aquaculture, genomic surveillance can be applied to fish, shrimp, pond water, sediments, feed, biofilms, and wastewater. It also enables analysis of the **resistome**, the complete collection of antimicrobial resistance genes present in pathogenic and environmental

microorganisms, providing valuable insights into the spread and evolution of resistance within aquatic ecosystems (Lanza et al., 2018).

Importance of Genomic Surveillance in Aquaculture

Intensive aquaculture systems create favourable conditions for the emergence and dissemination of antimicrobial-resistant bacteria because of high stocking densities, environmental stress, and frequent antibiotic exposure. Genomic surveillance provides an effective early warning system by detecting resistance genes before resistant pathogens become widespread. It identifies the bacterial strains responsible for disease outbreaks, tracks transmission pathways among farms and aquatic environments, and supports evidence-based antibiotic stewardship. Furthermore, genomic surveillance contributes to the **One Health** approach by monitoring the movement of resistant bacteria between aquatic animals, the environment, and humans, thereby improving disease control and promoting sustainable aquaculture (WHO, 2023; FAO, 2024; Hendriksen et al., 2019).

Development of Antimicrobial Resistance

Antimicrobial resistance develops when bacteria evolve mechanisms that enable them to survive exposure to antibiotics. In aquaculture, the frequent and sometimes indiscriminate use of antimicrobial agents creates selective pressure, allowing resistant bacteria to proliferate while susceptible bacteria are eliminated (WHO, 2023). Resistance may arise through spontaneous genetic mutations or by acquiring antimicrobial resistance (AMR) genes from other bacteria via **horizontal gene transfer (HGT)**.

Horizontal gene transfer occurs through three principal mechanisms: **conjugation**, where plasmids carrying resistance genes are transferred between bacteria; **transformation**, involving the uptake of free DNA from the environment; and **transduction**, in which bacteriophages transfer genetic material between bacterial cells (Partridge et al., 2018). Mobile genetic elements such as plasmids, transposons, and integrons facilitate the rapid dissemination of AMR genes among both pathogenic and non-pathogenic bacteria, accelerating the emergence of multidrug-resistant (MDR) strains.

Aquatic environments act as important reservoirs of resistance genes because bacteria from fish, sediments, wastewater, and surrounding ecosystems continuously exchange genetic material. Consequently, aquaculture has become an important component of the global **One Health** framework addressing antimicrobial resistance (FAO, 2024; WHO, 2023).

Genomic Technologies Used for AMR Surveillance

Recent advances in genomic technologies have transformed antimicrobial resistance surveillance by enabling rapid identification of bacterial pathogens and comprehensive analysis of resistance genes. These tools provide greater accuracy and resolution than conventional culture-based methods, allowing researchers to monitor the evolution and spread of resistant microorganisms in real time.

Whole Genome Sequencing (WGS) is considered the gold standard for genomic surveillance. It determines the complete DNA sequence of bacterial isolates, enabling simultaneous identification of bacterial species, antimicrobial resistance genes, virulence factors, plasmids, and phylogenetic relationships. WGS also assists in outbreak investigations by determining whether bacterial isolates originate from a common source (Ellington et al., 2017).

Next-Generation Sequencing (NGS) enables high-throughput sequencing of millions of DNA fragments simultaneously, making it possible to analyse multiple bacterial genomes within a short time. Its speed and cost-effectiveness have made NGS an essential tool for large-scale AMR surveillance programmes (Goodwin et al., 2016).

Metagenomic sequencing analyses all genetic material present in environmental samples such as pond water, sediments, biofilms, and wastewater without the need for bacterial isolation. This approach identifies both culturable and unculturable microorganisms and provides a comprehensive overview of the **resistome**, facilitating early detection of emerging resistance genes (Lanza et al., 2018).

Portable sequencing platforms such as **Oxford Nanopore Technologies** enable near real-time genomic surveillance directly in field settings. Coupled with advanced bioinformatics and artificial intelligence, these technologies allow rapid interpretation of genomic data and support timely decision-making during disease outbreaks (Hendriksen et al., 2019).

Major Antimicrobial Resistance Genes and Resistant Pathogens in Aquaculture

Several bacterial pathogens of fish and shellfish have acquired antimicrobial resistance genes that compromise treatment efficacy. Common pathogens include *Aeromonas hydrophila*, *Vibrio parahaemolyticus*, *Edwardsiella tarda*, *Streptococcus agalactiae*, and *Flavobacterium columnare*. These bacteria frequently harbour resistance genes associated with tetracyclines (**tet**), sulfonamides (**sul**), quinolones (**qnr**), β-lactam antibiotics (**bla**), aminoglycosides (**aadA**), macrolides (**erm**), and, in some cases, colistin (**mcr**) (Cabello et al., 2013; Michael et al., 2023).

Genomic surveillance enables simultaneous detection of these resistance genes and the mobile genetic elements responsible for their dissemination. Monitoring their distribution provides valuable information on the emergence of multidrug-resistant bacterial strains, supports prudent antibiotic selection, and guides disease prevention strategies in aquaculture (Hendriksen et al., 2019).

Applications of Genomic Surveillance in Aquaculture

Genomic surveillance has become an indispensable tool for modern aquaculture by enabling rapid detection, monitoring, and control of antimicrobial-resistant pathogens. One of its major applications is the **early detection of resistance genes**, allowing researchers and veterinarians to identify emerging antimicrobial resistance before clinical disease outbreaks occur. This facilitates timely intervention and minimizes economic losses associated with bacterial infections (Hendriksen et al., 2019).

Whole genome sequencing also improves **outbreak investigations** by comparing bacterial genomes from different farms or geographical regions. This helps determine the origin of disease outbreaks, trace transmission routes, and distinguish between newly introduced pathogens and persistent farm-associated strains. Such information strengthens farm biosecurity and supports effective disease management strategies (Ellington et al., 2017).

Genomic surveillance further contributes to **antibiotic stewardship** by identifying the resistance profile of bacterial pathogens before treatment is initiated. Rather than relying on empirical antibiotic therapy, veterinarians can select the most effective antimicrobial agents based on genomic evidence, reducing unnecessary antibiotic use and slowing the development of resistance (WHO, 2023).

Another important application is **environmental monitoring**. Metagenomic analysis of pond water, sediments, wastewater, and biofilms enables continuous surveillance of antimicrobial resistance genes circulating in aquaculture ecosystems. These environmental reservoirs often serve as sources of resistant bacteria that can infect cultured aquatic animals and spread to surrounding environments (Lanza et al., 2018).

Finally, genomic surveillance supports **selective breeding programmes** by identifying fish populations naturally resistant to bacterial diseases. Integrating genomic information into breeding strategies may improve disease resistance, reduce antibiotic dependence, and promote sustainable aquaculture production (Houston et al., 2020).

Genomic Surveillance and the One Health Approach

Antimicrobial resistance is a **One Health** challenge because resistant bacteria and resistance genes move freely among aquatic animals, humans, and the environment. Antibiotics used in aquaculture may select for resistant bacteria that are subsequently released into surrounding water bodies through farm effluents. These bacteria or their resistance genes can spread to wild fish populations, other aquatic organisms, livestock, and humans through environmental contamination or the food chain (WHO, 2023).

Genomic surveillance provides an integrated platform for monitoring antimicrobial resistance across these interconnected sectors. By comparing bacterial genomes from aquaculture systems, clinical settings, food products, and environmental samples, scientists can identify common resistance genes, monitor their dissemination, and develop coordinated strategies to reduce AMR transmission. This integrated surveillance strengthens public health, protects aquatic ecosystems, and supports sustainable food production (FAO, 2024; WOAH, 2023).

Future Prospects

Rapid advances in sequencing technologies and computational biology are transforming genomic surveillance into a routine component of aquaculture health management. Portable sequencing devices, such as nanopore-based platforms, now enable near real-time genome sequencing directly at fish farms, allowing faster diagnosis of bacterial diseases and early detection of antimicrobial resistance (Quick et al., 2016).

Artificial intelligence and machine learning are increasingly being integrated with genomic surveillance to predict antimicrobial resistance patterns, identify novel resistance genes, and improve outbreak forecasting. These technologies enhance the speed and accuracy of genomic data analysis, supporting evidence-based decision-making for disease control (Hendriksen et al., 2019).

Future research is expected to integrate genomic surveillance with transcriptomics, proteomics, and environmental DNA (eDNA) monitoring to provide a comprehensive understanding of pathogen evolution and host–pathogen interactions. Expansion of international genomic surveillance networks and open-access AMR databases will further strengthen global monitoring of resistant pathogens and facilitate collaborative efforts to combat antimicrobial resistance in aquaculture (FAO, 2024).

Conclusion

Antimicrobial resistance poses a serious threat to sustainable aquaculture, animal health, and global food security. Conventional surveillance methods alone are insufficient to monitor the rapid emergence and spread of resistant bacteria. Genomic surveillance, through technologies such as Whole Genome Sequencing, Next-Generation Sequencing, and metagenomics, provides powerful tools for detecting resistance genes, tracking pathogen evolution, and understanding transmission dynamics. By supporting early disease detection, antibiotic stewardship, biosecurity, and the One Health approach, genomic surveillance is transforming the management of bacterial diseases in aquaculture. Continued investment in genomic technologies, bioinformatics infrastructure, and international collaboration will be essential for mitigating antimicrobial resistance and ensuring resilient and sustainable aquaculture systems for the future.

Refrences

Cabello, F. C., Godfrey, H. P., Buschmann, A. H., & Dölz, H. J. (2013). Aquaculture as yet another environmental gateway to the development and globalisation of antimicrobial resistance. *The Lancet Infectious Diseases, 13*(10), 83–90. https://doi.org/10.1016/S1473-3099(13)70100-6

Ellington, M. J., Ekelund, O., Aarestrup, F. M., Cantón, R., Doumith, M., Giske, C., et al. (2017). The role of whole genome sequencing in antimicrobial susceptibility testing of bacteria. *Journal of Antimicrobial Chemotherapy, 72*(5), 1275–1283. https://doi.org/10.1093/jac/dkw551

Food and Agriculture Organization of the United Nations. (2024). *The State of World Fisheries and Aquaculture 2024: Blue Transformation in Action*. FAO. https://doi.org/10.4060/cd0683en

Goodwin, S., McPherson, J. D., & McCombie, W. R. (2016). Coming of age: Ten years of next-generation sequencing technologies. *Nature Reviews Genetics, 17*(6), 333–351. https://doi.org/10.1038/nrg.2016.49

Hendriksen, R. S., Munk, P., Njage, P., et al. (2019). Global monitoring of antimicrobial resistance based on metagenomics analyses of urban sewage. *Nature Communications, 10*, 1124. https://doi.org/10.1038/s41467-019-08853-3

Houston, R. D., Bean, T. P., Macqueen, D. J., et al. (2020). Harnessing genomics to fast-track genetic improvement in aquaculture. *Nature Reviews Genetics, 21*(7), 389–409. https://doi.org/10.1038/s41576-020-0227-y

Partridge, S. R., Kwong, S. M., Firth, N., & Jensen, S. O. (2018). Mobile genetic elements associated with antimicrobial resistance. *Clinical Microbiology Reviews, 31*(4), e00088-17. https://doi.org/10.1128/CMR.00088-17

World Health Organization. (2023). *Global antimicrobial resistance and use surveillance system (GLASS) report 2023*. World Health Organization.

Volume: 06 Issue No: 09

FOLIAR NUTRITION IN PULSES IMPROVES THE GRAIN YIELD!

Article ID: AG-VO6-I09-34

***K.Kalaichelvi and P. Murali Sankar**

Assistant Professor (Agronomy), KVK, TNAU, Vridhachalam – 606001, Tamil Nadu, India

Assistant Professor (Plant Pathology), RVS Horticultural College, Sempatti – 624707, TN, India

*Corresponding Author: K.Kalaichelvi

Introduction

Source-sink relationship is improved due to rapid translocation of nutrients from leaves to the developing pods. Additional nutrition through foliar feeding plays a vital role in pulse production by stimulating root development, nodulation, energy transformation, metabolic processes and pod setting. It is also recognized that supplementary foliar fertilization during crop growth can improve the mineral status of plants and increase the crop yield. Production of major pulses is constrained by both biotic and abiotic stresses. The foliar application of nutrients could be ascribed to quick access to nutrients by plants at seedling and early development stages. Retention of flowers is possible through foliar application of macronutrients during flower initiation and pod development stages along with soil application of micronutrients. Foliar application is credited with the advantage of quick and efficient utilization of nutrients, elimination of losses through leaching, fixation and regulating the uptake of nutrients by plant. Among the micronutrients Zn, Fe, B, Mn and Mo improved the yield appreciably and foliar spray of micronutrients proved to be economical in pulses. The following inputs may be applied for improving the yield of pulses.

Urea

Urea is the most concentrated solid nitrogenous fertilizer, containing 46% nitrogen. As a source of nitrogen, it improves the vegetative growth, leaf chlorophyll content and leaf area index and yield of crops. Many findings are confirmed the advantages of urea spray in black gram at 1 to 2% concentration. Foliar application of N may solve slow growth, nodule

senescence and low seed yield of pulse. 1% urea at floral initiation and 15 days after flowering in black gram registered higher growth, yield parameters and yield. Found that an increment in grain yield was 27.4 to 31.0% due to foliar spray of 2% urea solution at 40 days after sowing in different black gram varieties. Foliar spray of 2% urea significantly improved the growth parameters, physiological parameters like chlorophyll content, soluble protein and nitrate reeducates activity in black gram and ultimately increased the grain yield to the tune of 20% over control .

DAP

Di ammonium phosphate (DAP) is the world's most widely used phosphorus fertilizer. It is an excellent source of phosphorus (P) and nitrogen (N) for plants. Foliar spray of DAP increased the photosynthetic ability which resulted in increased accumulation of dry matter and also efficient portioning of photosynthates towards sink. Foliar spray of DAP met constant requirement of nitrogen and phosphorus at reproductive stage of the crop and improves the yield components like number of pods per plant, number of seeds per pod, pod length and test weight, which had direct influence on the grain yield.

DAP+ Micronutrients

High temperature and moisture stress at the reproductive stage in pulses (lentils) reduced grain yield by reducing chlorophyll contents and impairing photosynthesis. Exogenous application of micronutrients (Zn, Fe, and B) ameliorated the stress effects. In particular, B+Fe and B+Zn+Fe upregulated antioxidant enzyme activities, improved chlorophyll content, net photosynthetic rate, water relations, and yield.

Quality parameters such as seed protein content and seed total free amino acid content were enhanced by the foliar application of 0.5% KNO3 + 2% DAP + micronutrient spray. Foliar application of DAP 2% + 0.50% ZnSO4 + 0.50% FeSO4 + 0.10%boric acid + 0.05% sodium molybdate + 0.05% cobalt chloride recorded the highest plant height, dry matter production, number of pods per plant, seeds per pod, test weight, grain yield and haulm yield over control.

2%DAP+1% Kcl

NPK uptake and yield were significantly influenced when foliar spray of 2% DAP+1% KCl was given at flowering and pod filling stages of crop growth.

DAP+NAA 40 ppm

Maximum number of nodules per plant (34.78) was recorded in treatment (DAP @ 1% + NAA

@40ppm along with Recommended Dose of Fertilizers.

DAP+$ZnSO_4$

2% Spray of DAP + 0.5% Spray of ZnSO4 at pre-flowering and pod initiation stage) found higher for yield and yield attributes .

2 %DAP + salicylic acid @ 75 ppm

Foliar application of DAP @ 2 % + salicylic acid @ 75 ppm at flower initiation was found beneficial for growth and yield of greengram along with higher growth attributes, net returns and BC ratio.

DAP + Growth hormones +Micronutrients

Foliar application of 2% DAP + NAA 40 ppm +B 0.2% + Mo 0.05% at 30 DAS significantly increased the height and dry weight of plants, number of pods per plant, seeds/pod, test weight, grain yield and haulm yield over the control. Foliar application of DAP 2% + NAA 40 ppm + ZnSO4 0.5 % + FeSO4 1% twice at pre flowering, flowering stage recorded significantly higher reproductive efficiency and grain yield in rice fallow black gram. Use of micronutrients like Zinc (Zn), Iron (Fe), Boron (B), Manganese (Mn), Molybdenum (Mo), Copper (Cu), Cobalt (Co) and Nickel (Ni) has now become a common practice to increase crop yield especially under adverse environmental conditions in pulses. Foliar spray of micronutrients improve flowering, pollen production capacity, pollen viability, stigma receptivity and pollen-stigma interaction and also increased the yield parameters like numbers, size and weight of pod and seeds.

Complex fertilizers

19:19:19

Complex fertilizers supply all three primary nutrients (NPK). Foliar application of 3% NPK (19-19-19) recorded higher seed yield of black gram.

18:18:18

18-18-18 mix is a balanced liquid N-P-K fertilizer, suitable for all crops, during all stages of plant growth. 18-18-18 mix liquid fertilizer provides an additional source of nitrogen, phosphorous and potassium during the growing season. 18-18-18 mix liquid fertilizer is in the form readily absorbed by plant tissue. 18-18-18 mix is manufactured by utilizing quality raw materials to provide a very agronomically efficient source of N-P-K. The quality of the raw materials used to formulate 18-18-18 mix maximized plant nutrient solubility.

Panchagavya

Panchagavya, an organic product has potential to play the role in promoting growth and providing immunity in plant system. The use of fermented cow dung, urine, milk fat, curd and milk with the name of Panchagavya is getting adaptive popularity in Indian agriculture. Increased plant height may be due to increase in protein synthesis and growth regulators such as IAA and GA3, in panchagavya may enhanced the cell division, cell multiplication and cell enlargement which favours increased inter nodal length and favours translocation of more photo-assimilates to reproductive parts thereby induces early flowering . Foliar spray of 3% panchagavya at 15th, 25th, 35th and 45th days interval period recorded significantly higher growth and yield black gram than control .

TNAU Pulse Wonder

The department of Crop Physiology of Tamil Nadu Agricultural University (TNAU) Coimbatore has developed a crop booster to improve the yield potential of pulses. TNAU pulse wonder, as it is know, has been specifically designed to increase the yield of blackgram and greengram. This pulse wonder was developed by studying the physiological and nutritional disorders that occur in different stages of pulse crop. TNAU pulse wonder contains macro and micro nutrients and promotes better growth and development for the pulse crop. Apart from this, it has a lot of other advantages as well. It replaces the existing practise of diammonium phosphate foliar spray. TNAU pulse wonder is contains ingredients that are water soluble and facilitates complete absorption of nutrients and drought tolerant.

Conclusion

Foliar application of different sources of nutrients supplying major nutrients and micronutrients at 30 and 45 DAS improved the yield attributes, grain yield and quality parameters. Hence according to the requirement pulse growers can use Urea, DAP, DAP+ Micronutrients (DAP 2% + 0.50% ZnSO4 + 0.50% FeSO4 + 0.10%boric acid + 0.05% sodium molybdate + 0.05% cobalt chloride), 2%DAP+1% Kcl, DAP+NAA 40 ppm, 2% DAP+0.5% $ZnSO_4$, DAP @ 2 % + salicylic acid @ 75 ppm , Complex fertilizers, Panchagavya and TNAU pulse wonder for improving the yield attributes and Yield. Moreover this practice, arrest the flower dropping in pulse crops which is the major setback in pulse production hence this is an opportunity for overall increase in pulse production.

Volume: 06 Issue No: 09

FOOD WASTE: VITAMIN B12 RECOVERY AND FOOD APPLICATIONS

Article ID: AG-VO6-I09-35

Dr.G.Amuthaselvi

Assistant Professor, Department of Food Process Engineering

AEC&RI, TNAU, Coimbatore- 641 003, Tamil Nadu, India

Introduction

Vitamin B12, commonly referred to as cobalamin, is an essential water-soluble micronutrient with important roles in human metabolism. It is required for DNA synthesis, red blood cell formation, neurological function and the metabolism of certain amino acids and fatty acids. Vitamin B12 is particularly important because humans cannot synthesize it and therefore depend on dietary sources or supplementation. The recommended intake for adults is approximately 2.4 µg/day, while requirements increase slightly during pregnancy and lactation. The natural occurrence of nutritionally active vitamin B12 is strongly associated with microorganisms and animal-derived foods rather than higher plants. Certain bacteria and archaea possess the biochemical pathways required for de novo cobalamin biosynthesis, whereas humans and higher plants cannot synthesize vitamin B12.

The increasing generation of food waste has created both an environmental problem and an opportunity for nutrient recovery. Food loss and waste occur throughout the food supply chain, including agricultural production, processing, distribution, retail and consumption. The Food and Agriculture Organization has highlighted food loss and waste as an important sustainability challenge because it contributes to resource wastage, environmental pollution and greenhouse-gas emissions. Current FAO information indicates that approximately 13.2% of food is lost after harvest and before retail, while a further 19% is wasted at retail, food-service and household levels. Consequently, the conversion of food waste into high-value products such as proteins, vitamins, enzymes, organic acids and microbial biomass has become an important research area.

Vitamin B12 presents a particularly interesting opportunity because it is a high-value micronutrient and its industrial production already relies predominantly on microbial fermentation. The complexity of the cobalamin molecule makes chemical synthesis unattractive at industrial scale, and fermentation using selected microorganisms has become the principal production route. Important industrial microorganisms include *Propionibacterium freudenreichii* and strains related to *Pseudomonas denitrificans*. The use of food waste as an inexpensive nutrient substrate for these microorganisms could potentially reduce the cost and environmental impact of B12 production while simultaneously addressing the problem of food-waste disposal.

An important distinction should be made between recovering vitamin B12 already present in food waste and producing vitamin B12 using food waste as a fermentation substrate. Animal-derived processing residues such as fish viscera, liver, meat residues, poultry residues, eggs and dairy streams may contain naturally occurring B12. In contrast, most plant-derived wastes, including cereal bran, fruit peels, vegetable residues and oilseed cakes, should not be considered reliable direct sources of active B12. Instead, such residues may be used as substrates for microorganisms capable of producing B12. This distinction is particularly important when developing a research project involving plant protein and agricultural waste.

Chemistry and Forms of Vitamin B12

Vitamin B12 belongs to a family of cobalt-containing compounds known as corrinoids. The basic structure contains a corrin ring surrounding a central cobalt atom. Different upper ligands produce different forms of cobalamin, including methylcobalamin, adenosylcobalamin, hydroxocobalamin and cyanocobalamin. Methylcobalamin and adenosylcobalamin are important coenzyme forms involved in human metabolism, whereas cyanocobalamin is a chemically stable form widely used in commercial supplements and food fortification.

The distinction between biologically active vitamin B12 and other corrinoids is extremely important in food-waste research. Analytical methods that detect total corrinoids or use nonspecific microbiological assays may overestimate nutritionally useful vitamin B12. Some foods contain compounds structurally related to B12 but these may not be active in humans. For example, pseudovitamin B12 is a corrinoid that can occur in some microbial and algal foods but does not have the same nutritional activity as human-active cobalamins. Recent research has emphasized the importance of distinguishing active B12 from inactive corrinoids using chemically specific analytical approaches.

The importance of this distinction has increased with the development of plant-based foods and alternative protein products. A product may show a measurable "B12" value in a microbiological assay without necessarily providing an equivalent amount of biologically active B12 to the consumer. Therefore, research involving B12 recovery from food waste should ideally employ a validated analytical method capable of identifying the specific cobalamin forms present. Liquid chromatography coupled with mass spectrometry, particularly LC-MS/MS, is increasingly useful for characterizing individual corrinoids and determining whether the detected compounds correspond to nutritionally relevant cobalamins.

Physiological Importance of Vitamin B12

Vitamin B12 participates in several essential biochemical reactions. In humans, it acts as a cofactor for methionine synthase and methylmalonyl-CoA mutase. Methionine synthase participates in the conversion of homocysteine to methionine and is connected to folate metabolism and DNA synthesis. Methylmalonyl-CoA mutase participates in the metabolism of certain amino acids and odd-chain fatty acids. Consequently, inadequate B12 status can affect blood formation, cellular metabolism and neurological function.

Vitamin B12 deficiency can result from inadequate dietary intake, impaired absorption or certain medical conditions. Individuals consuming diets with little or no animal-derived food may be at increased risk if fortified foods or supplements are not consumed. This has increased interest in the development of B12-containing or B12-fortified plant-based foods. Reviews of vitamin B12 nutrition have highlighted the need for reliable sources of active B12 for vegetarian and vegan populations.

The relationship between food waste and B12 is therefore important from both nutritional and environmental perspectives. If B12-containing processing residues can be safely recovered, they could provide a source of valuable micronutrients. Alternatively, if plant-based waste is converted through microbial fermentation into B12-containing biomass or food ingredients, the same waste stream could contribute to the development of nutritionally improved foods.

Food Waste as a Resource for Vitamin B12

Food waste is a heterogeneous material consisting of carbohydrates, proteins, lipids, minerals, vitamins and other organic compounds. Its composition varies according to the source. Fruit and vegetable residues are often rich in soluble sugars, fibre and minerals; cereal-processing residues contain starch, protein and fibre; oilseed cakes contain considerable protein

and residual carbohydrates; and brewery residues may contain protein, fibre and fermentable nutrients. Such components can potentially support microbial growth.

The use of food waste as a fermentation substrate provides an alternative to conventional synthetic or purified fermentation media. Microorganisms require carbon, nitrogen, minerals and other growth factors for biomass production and metabolite synthesis. If these nutrients are supplied by food-processing residues, the quantity of expensive refined nutrients required in the fermentation medium may be reduced. A recent review specifically examining vitamin B12 production from agro-industrial and food waste identified fruit and vegetable skins, brewery spent grain and other agro-industrial residues as potential substrates for microbial cobalamin production. However, food waste cannot be used directly without characterization and pretreatment. Variations in moisture, pH, carbohydrate composition, protein concentration and inhibitory compounds can influence microbial growth. The substrate may also contain undesirable microorganisms or contaminants. Therefore, a food-waste-to-B12 process must include appropriate stabilization, pretreatment, fermentation control and downstream purification.

Direct Recovery of Vitamin B12 from Animal-Derived Food Waste

Animal-derived food-processing residues are fundamentally different from plant residues because they may naturally contain vitamin B12. Meat, fish, poultry, eggs and dairy products are recognized dietary sources of B12. Therefore, processing residues from these materials may contain residual vitamin B12 depending on the tissue and processing conditions. Fish-processing waste is a particularly interesting material because fish industries generate large amounts of heads, viscera, skin, bones and trimming fractions. Fish viscera and organs can contain proteins, lipids, minerals and vitamins and may therefore be considered valuable rather than disposable materials. However, the actual B12 concentration can vary substantially between fish species and tissues. Consequently, direct measurement is necessary before selecting a waste stream for B12 recovery.

Liver and other organ tissues are particularly important because animal organs can contain relatively high concentrations of B12 compared with many other tissues. Historical nutritional research identified liver as an important source of the anti-pernicious-anemia factor that was later identified as vitamin B12. Modern industrial B12 production, however, is based

primarily on microbial fermentation rather than extraction from animal tissues because fermentation offers better control and scalability.

Meat and poultry processing wastes can also contain B12. Blood, liver, viscera and trimming residues may contain different concentrations of cobalamin. The direct extraction of B12 from these materials would require efficient separation and purification procedures, together with strict microbiological and chemical safety controls. For food-grade applications, the source material would have to be carefully monitored for pathogens, antibiotic residues, heavy metals and other contaminants.

Egg-processing residues may also contain B12 because eggs are recognized dietary sources of the vitamin. However, egg waste would generally be more attractive for integrated recovery of protein and other nutrients than for B12 alone. For example, egg white and egg yolk processing streams could be separately evaluated for proteins, lipids, phospholipids and micronutrients, while B12 could be measured as one component of the recovered nutrient profile.

Dairy-processing streams also represent potential sources of B12 because milk and dairy products naturally contain cobalamin. Whey, for example, is already extensively utilized for protein recovery. An integrated dairy biorefinery could potentially recover whey proteins while simultaneously evaluating B12 and other micronutrients. Nevertheless, the concentration and stability of B12 during pasteurization, drying and other processing operations need to be determined experimentally.

Plant Food Waste and Vitamin B12

Plant-derived food waste requires special consideration because higher plants generally do not synthesize vitamin B12. This means that materials such as groundnut cake, soybean okara, rice bran, wheat bran, fruit peels and vegetable residues cannot automatically be assumed to contain nutritionally significant active B12. The absence of natural B12 from most unfortified plant foods is one reason why vitamin B12 fortification and microbial biofortification have received increasing attention.

Some plant-derived foods have nevertheless been reported to contain measurable B12 or B12-related compounds. Purple laver or nori is one well-known example, and some mushrooms and fermented foods have also been investigated. However, the origin and bioactivity of these compounds must be established carefully because microbial contamination or associated microorganisms can contribute corrinoids. Watanabe and colleagues emphasized that the

presence of corrinoids does not necessarily mean that all detected compounds are active vitamin B12.

This is particularly relevant to research on agricultural waste. If a plant waste sample is tested for B12 and a positive value is obtained, the researcher should not immediately conclude that the plant itself contains naturally synthesized B12. The result should be confirmed using a specific analytical technique. The possibility of microbial contamination, fermentation-derived B12 or inactive corrinoids should be considered.

Microbial Production of Vitamin B12 from Food Waste

Microbial fermentation represents the most promising approach for converting plant-based food waste into vitamin B12. In this approach, food waste acts as a substrate rather than as the direct source of B12. Selected microorganisms are cultivated using nutrients derived from the waste, and the microorganisms synthesize cobalamin during growth or under specific production conditions. Vitamin B12 biosynthesis is restricted to particular microorganisms, especially certain bacteria and archaea. The biosynthetic pathway is complex and involves numerous enzymatic reactions. Two major routes have been described: an aerobic pathway and an anaerobic pathway. Certain microorganisms can also salvage corrinoid intermediates from their environment.

Among the microorganisms investigated for industrial B12 production, *Propionibacterium freudenreichii* is particularly important because it can produce physiologically active B12 and has a history of use in food fermentation. *Pseudomonas denitrificans* and related strains have also been widely studied for industrial cobalamin production.)

Propionibacterium freudenreichii as a B12 Producer

Propionibacterium freudenreichii is one of the most interesting microorganisms for food-related vitamin B12 production. It is a Gram-positive bacterium traditionally associated with dairy fermentation and Swiss-type cheese production. Its importance in B12 production arises from its ability to synthesize physiologically active cobalamin under appropriate conditions.

The fermentation behaviour of *P. freudenreichii* is unusual because different stages of its cobalamin biosynthesis have different oxygen requirements. Industrial and research processes can therefore employ controlled fermentation conditions in which an initial low-oxygen or anaerobic phase supports parts of the pathway, followed by carefully controlled aeration or

microaeration to support the synthesis of the lower ligand required for active cobalamin formation. Reviews describe two-stage fermentation strategies in which the second stage involves controlled aeration.

This characteristic makes process control extremely important. Temperature, pH, oxygen concentration, substrate composition, cobalt availability and fermentation time can influence B12 production. The use of food waste as a substrate therefore requires systematic optimization to ensure that the waste-derived medium supports both microbial growth and cobalamin biosynthesis.

Pseudomonas denitrificans and Industrial Production

Pseudomonas denitrificans has historically been one of the important microorganisms used for industrial vitamin B12 production. It follows an aerobic biosynthetic route and can produce high levels of cobalamin under controlled fermentation conditions. Industrial processes have used large fermenters with controlled temperature, pH, aeration and nutrient supply. The industrial fermentation of *P. denitrificans* demonstrates the importance of process engineering in vitamin production. Parameters such as dissolved oxygen and carbon dioxide can influence productivity. Research into dissolved oxygen control has shown that staged control of oxygen availability can improve cobalamin production. For food-waste applications, however, the suitability of a microorganism must be considered not only from the perspective of yield but also from food safety, regulatory acceptance and downstream purification requirements. A microorganism suitable for industrial chemical production may not necessarily be suitable for direct use in food fermentation. Therefore, microbial selection should be based on both productivity and food-safety considerations.

Selection of Food Waste Substrates

The selection of an appropriate food waste is one of the most important stages in developing a B12 fermentation process. An ideal substrate should be inexpensive, readily available, nutritionally suitable, safe and capable of supporting high microbial productivity. It should preferably contain fermentable carbohydrates, nitrogen-containing compounds and minerals. Fruit and vegetable residues are attractive because many contain soluble sugars and readily degradable carbohydrates. However, some fruit wastes can contain organic acids, essential oils or phenolic compounds that may inhibit microbial growth. Pretreatment or dilution may therefore be required.

Brewery spent grain is another potentially useful substrate. It contains proteins, fibre, residual carbohydrates and minerals. Although much of the easily fermentable carbohydrate is removed during brewing, the remaining material can still provide nutrients for microbial processes after suitable hydrolysis. The recent literature on waste-based B12 production specifically identifies spent grain as a potential substrate. Cereal-processing residues such as rice bran, wheat bran and maize by-products may also be investigated. Their carbohydrate and protein contents make them interesting candidates for microbial fermentation. Enzymatic hydrolysis can release fermentable sugars from complex polysaccharides and thereby improve substrate availability.

Oilseed-processing residues, including deoiled groundnut cake, soybean cake and other oilseed meals, are particularly attractive in a combined protein and B12 biorefinery. Protein can first be recovered from the material, after which the residual carbohydrate-containing fraction could potentially be converted into a fermentation substrate. This approach would maximize resource recovery.

Pretreatment of Food Waste

Pretreatment is necessary to make food waste suitable for controlled microbial fermentation. The first stage generally involves sorting and removal of foreign materials. This should be followed by washing where appropriate, size reduction and stabilization. High-moisture waste may require drying or other preservation methods if it is not immediately processed. Thermal treatment can be used to reduce the microbial load and improve storage stability. However, excessive heat may degrade sugars, generate inhibitory compounds or reduce the nutritional quality of the substrate. Therefore, mild stabilization conditions should be considered.

Enzymatic hydrolysis can be used when the waste contains complex carbohydrates. Cellulases, hemicellulases, amylases or other enzymes can convert polymers into smaller fermentable sugars. Acid or alkaline hydrolysis can also be used, but these methods may generate inhibitory compounds if poorly controlled. Physical methods such as grinding, milling and extrusion can improve surface area and facilitate subsequent hydrolysis. Ultrasound may also improve mass transfer and extraction of soluble components from certain residues. The optimum pretreatment depends on the characteristics of the selected waste.

Preparation of Fermentation Medium

After pretreatment, the food-waste material can be converted into a fermentation medium. The substrate concentration should be adjusted according to the tolerance and nutritional requirements of the selected microorganism. Excessive substrate concentration may increase viscosity or result in osmotic stress, while insufficient substrate may limit microbial growth. The medium may require supplementation with nitrogen, minerals, cobalt and other nutrients. Cobalt is particularly important because it forms the central metal atom of cobalamin. Other precursors or cofactors may also influence B12 biosynthesis. Research on microbial B12 production has investigated supplementation with cobalt ions, 5-aminolevulinic acid, dimethylbenzimidazole and other pathway-related compounds.

For a food-waste-based process, supplementation should be minimized where possible to preserve the economic and environmental advantages of using waste. However, some supplementation may be necessary to achieve satisfactory yields. Therefore, optimization should compare the additional cost of supplementation with the increase in B12 productivity.

Fermentation Process

The fermentation stage involves inoculation of the prepared food-waste medium with the selected microorganism under controlled conditions. Important parameters include temperature, pH, inoculum concentration, substrate concentration, agitation, aeration and fermentation time. These parameters interact with one another, making optimization essential.

For *P. freudenreichii*, fermentation can involve controlled oxygen conditions because different steps of cobalamin biosynthesis have different requirements. Literature describes processes in which initial growth occurs under oxygen-limited conditions followed by a controlled aeration phase. Fermentation may be performed in submerged liquid culture or, depending on the substrate, potentially through solid-state fermentation. Submerged fermentation offers better control of pH, temperature and oxygen and is therefore attractive for industrial B12 production. Solid-state fermentation may provide advantages when using agricultural residues with relatively low moisture content, but controlling heat, oxygen and moisture distribution can be more difficult.

Optimization of Vitamin B12 Production

Optimization is essential for developing a practical waste-based B12 production process. Response Surface Methodology can be used to evaluate the effects of several variables

simultaneously. For example, pH, temperature, fermentation time, inoculum concentration, substrate concentration and cobalt concentration can be selected as independent variables, while B12 concentration or productivity is used as the response. A statistical experimental design can reduce the number of experiments required compared with changing one factor at a time. Once the optimum region is identified, validation experiments should be conducted using the predicted optimum conditions. The process should then be evaluated for reproducibility.

The use of artificial intelligence and machine learning may provide additional opportunities for optimization. Large experimental datasets can be used to establish relationships between substrate composition, fermentation conditions and B12 yield. Such approaches may eventually assist in predicting the suitability of different food-waste streams before large-scale trials.

Role of Cobalt in B12 Biosynthesis

Cobalt is a unique component of vitamin B12 and therefore plays a central role in its biosynthesis. The availability of cobalt in the fermentation medium can affect cobalamin production. However, simply adding increasing concentrations of cobalt does not necessarily result in proportionally higher B12 production. Excessive concentrations may adversely affect microbial growth or create downstream processing concerns.

The optimum cobalt concentration depends on the microorganism and fermentation system. Therefore, cobalt supplementation should be experimentally optimized rather than selected arbitrarily. The final product should also be tested for residual cobalt and other minerals when intended for food applications.

Downstream Processing

After fermentation, vitamin B12 may be present intracellularly, extracellularly or in different forms depending on the microorganism and process conditions. The fermentation broth therefore requires downstream processing to recover the desired product. The first step may involve separation of microbial cells from the fermentation medium. Centrifugation or filtration can be employed. If B12 is predominantly intracellular, cell disruption may be required. Mechanical disruption, thermal treatment or chemical extraction can release intracellular cobalamin.

Because different cobalamin forms may be present, the extract may require conversion or purification before final use. Industrial processes commonly use stable forms such as

cyanocobalamin for commercial applications. However, the selection of the final form depends on the intended application and regulatory requirements. Purification may involve adsorption, precipitation, membrane separation, chromatography or combinations of these methods. The complexity and cost of downstream processing are important factors determining the economic feasibility of the overall process.

Analytical Determination of Vitamin B12

Accurate B12 analysis is essential for food-waste research. Microbiological assays have historically been used to estimate B12 because certain microorganisms require cobalamin for growth. However, microbiological assays may detect compounds with B12-like activity that are not necessarily active B12 in humans. Chromatographic methods provide greater specificity. High-performance liquid chromatography can separate individual cobalamin forms, while LC-MS/MS can provide more detailed molecular identification. Recent research has emphasized the need for "cobamide fingerprinting" to distinguish active B12 from inactive corrinoids. For a research project, it is therefore preferable to report not only "total B12" but also the analytical method used, the specific cobalamin form detected and, where possible, the biological relevance of the measured compound. This will improve the scientific validity of the results.

Stability of Vitamin B12 During Processing

Vitamin B12 stability is another important consideration. Processing operations such as heating, drying, exposure to light and prolonged storage can affect B12 content and activity. Research has shown that vitamin B12 may undergo degradation during cooking and storage, although the extent depends on the food matrix and processing conditions. Therefore, if a B12-enriched protein ingredient is developed, the vitamin should be measured immediately after processing and during storage. Parameters such as moisture content, water activity, temperature, light exposure and packaging material should be considered. A suitable packaging system can help protect the vitamin from environmental degradation. The interaction between B12 and the food matrix is also important. Proteins, minerals, polyphenols and other compounds may influence B12 stability or bioavailability. Consequently, B12 stability should ideally be studied in the actual finished product rather than only in a purified laboratory solution.

Vitamin B12-Enriched Plant Protein

One of the most promising applications of food-waste-derived B12 is the development of B12-enriched plant protein products. Plant proteins recovered from oilseed cakes, cereal residues

and pulse-processing wastes can provide protein, while microbial fermentation or controlled fortification can provide vitamin B12. For example, deoiled groundnut cake can be processed to obtain a protein isolate. The protein isolate could then be incorporated into a food product such as a meat analogue, protein beverage or nutrition bar. A B12-producing fermentation step could potentially be integrated into the process, or a validated B12 preparation could be added during formulation. The concept is particularly relevant because unfortified plant-based protein foods generally do not provide reliable amounts of active B12. Microbial fermentation has therefore been investigated as a means of increasing B12 in plant-based foods. Recent literature describes the potential of *P. freudenreichii* and other microorganisms for producing B12-enriched plant matrices.

Fermented Plant Foods as B12 Sources

Fermentation provides an interesting route for increasing the nutritional value of plant-based foods. Microorganisms can transform food substrates and produce vitamins, organic acids, peptides and other metabolites. Recent research has demonstrated interest in using B12-producing microorganisms to enrich plant-based foods. A recent study investigated vitamin B12 synthesis in sauerkraut juice using *P. freudenreichii* fermentation and reported approximately 1.62 µg B12 per 100 mL in the enriched ferment. The study illustrates how an underutilized food stream can potentially be transformed into a B12-containing food product through controlled microbial fermentation.

Application in Plant-Based Meat Products

Plant-based meat analogues are an important potential application for B12-enriched protein obtained through food-waste valorization. The protein component can be obtained from oilseed cakes, pulse residues or other plant-processing streams, while B12 can be incorporated through microbial biofortification or controlled fortification. A typical plant-based meat analogue contains plant protein, water, vegetable oil, carbohydrates, fibre, hydrocolloids, flavour compounds and other functional ingredients. The protein contributes to structure and texture, while the oil contributes to juiciness and mouthfeel. If the product is intended as a nutritional alternative to meat, vitamin B12 can be an important micronutrient. The incorporation of B12 must be carefully controlled because excessive or insufficient levels may create nutritional or regulatory problems. Stability during extrusion and cooking should also be evaluated. Therefore,

B12 concentration should be measured before processing, immediately after processing and during storage.

Application in Protein Beverages

B12-enriched plant protein beverages represent another potential application. Protein obtained from groundnut cake, soybean residue, cereal bran or pulse-processing by-products could be used as the protein base. B12 could be introduced through microbial fermentation or validated fortification. For beverages, protein solubility is a major consideration. Protein isolates with poor solubility can produce sedimentation and undesirable mouthfeel. Processing such as homogenization, ultrasound treatment or enzymatic modification may improve protein dispersion. The stability of B12 during beverage processing and storage should also be evaluated. Factors such as pH, light, temperature and oxygen can influence vitamin stability. Therefore, packaging and storage conditions should be selected to maintain the nutritional quality of the final product.

Application in Bakery Products

B12-enriched protein ingredients can potentially be incorporated into bread, biscuits, cookies, crackers and nutrition bars. Protein recovery from food waste can increase the nutritional value of these products while reducing waste. However, baking involves relatively high temperatures, which may affect B12 stability. Consequently, if B12 is added to bakery products, the retention percentage should be measured after baking. The timing of addition, encapsulation, protective food matrices and packaging may be investigated to improve retention. Protein addition can also influence dough properties and product quality. Therefore, the optimum level of protein incorporation should be determined through rheological, physical and sensory studies.

Application in Nutritional Supplements

Protein-rich nutritional powders containing B12. Protein isolates recovered from food-processing residues can serve as the protein base, while microbial B12 can provide micronutrient fortification. Such products could be developed as nutrition powders, meal-replacement ingredients or specialized food formulations. However, the safety and regulatory requirements for supplements and fortified foods must be considered carefully. The final product should be standardized for protein and B12 content and tested for microbial safety, heavy metals and other contaminants.

Integrated Biorefinery Approach

A particularly promising concept is the development of an integrated food-waste biorefinery. Instead of recovering only one product from a residue, several valuable components can be obtained sequentially. For example, an oilseed-processing residue could first undergo protein extraction. The protein isolate could be used as a food ingredient, while the remaining carbohydrate-rich fraction could be hydrolysed and used as a microbial fermentation substrate. The fermentation step could then produce vitamin B12 or other high-value metabolites. After fermentation, the residual biomass could potentially be used as animal feed, fertilizer, biogas substrate or another industrial resource. Such cascading utilization maximizes the value extracted from the original biomass.

This concept is particularly consistent with circular bioeconomy principles because it minimizes waste and reduces the dependence on virgin raw materials. Recent reviews have specifically highlighted the integration of microbial B12 production with agro-industrial by-product valorization as a promising direction for sustainable production.

Environmental Benefits

The conversion of food waste into vitamin B12 can provide several environmental advantages. Food waste that would otherwise undergo uncontrolled decomposition can be redirected into a controlled bioprocess. The process can recover nutrients and reduce the demand for refined fermentation substrates. The environmental benefit becomes greater when multiple products are recovered from the same material. For example, protein extraction followed by B12 fermentation can generate more value from the same agricultural biomass than either process alone. However, the environmental performance should not be assumed automatically. Fermentation requires energy, water, nutrients and downstream purification. Therefore, life-cycle assessment should be conducted to compare the environmental impacts of waste-based B12 production with conventional production systems. Factors such as transportation distance, pretreatment energy, fermentation conditions, purification requirements and waste disposal should be included.

Economic Potential

The economic feasibility of B12 production from food waste depends on substrate availability, pretreatment cost, fermentation yield, downstream recovery efficiency and market value of the final product. Food waste itself may have a low raw-material cost, but collection and

transportation can be expensive. The use of locally available food-processing residues can reduce transportation costs. For example, residues generated in a food-processing cluster could be collected and processed within the same region. This approach may be particularly suitable for agricultural universities, food-processing parks and rural agro-industrial clusters. An integrated process is economically attractive because several products can be generated. Protein, B12, fibre and other bioactive compounds can potentially be recovered from the same biomass. Revenue from the primary product can therefore support the recovery of secondary products.

Safety Considerations

Food safety is one of the most important considerations in converting waste into food ingredients. Food waste may contain pathogenic microorganisms, mycotoxins, pesticide residues, heavy metals and other contaminants. Therefore, only suitable food-processing residues from controlled sources should be considered for food-grade B12 production. The selected microbial strain must also be properly characterized. The microorganism should have an appropriate food-safety profile and should not produce undesirable metabolites. Fermentation should be conducted under controlled hygienic conditions. If animal-derived food waste is used, additional concerns include pathogenic bacteria, antibiotic residues and other contaminants. Such materials require rigorous treatment and purification before any food application.

Regulatory Considerations

The use of food waste for production of food ingredients is subject to regulatory requirements. The status of the raw material, microorganism, processing method and final ingredient must be considered. A process suitable for laboratory research may not automatically be suitable for commercial food production. For microbial biofortification, the safety status of the microorganism is particularly important. *P. freudenreichii* has an established history of food use and has been studied extensively for B12 production. Nevertheless, the specific strain and intended application should be evaluated according to the regulations applicable in the target market. The final B12 concentration must also be verified using an appropriate analytical method. Claims concerning nutritional content should be based on validated analytical data and comply with applicable food-labelling regulations.

Challenges in B12 Production from Food Waste

One of the major challenges is the variability of food waste. Different batches may contain different concentrations of carbohydrates, proteins, minerals and inhibitory compounds.

This variability can affect microbial growth and B12 productivity. Another challenge is the presence of competing microorganisms. Food waste naturally contains bacteria, yeasts and moulds. Without adequate pretreatment and fermentation control, these organisms may compete with the selected B12-producing microorganism.

The presence of phenolic compounds, organic acids and other inhibitory substances may also reduce microbial growth. Pretreatment should therefore be optimized to increase substrate availability while minimizing inhibitors. Downstream purification is another major challenge. B12 is produced at relatively low concentrations compared with the bulk components of the fermentation medium. Recovery therefore requires efficient separation and concentration technologies.

Conclusion

Vitamin B12 is an essential micronutrient with important functions in DNA synthesis, blood formation and neurological metabolism. Because humans cannot synthesize B12 and higher plants generally do not produce active cobalamin, reliable dietary sources are important. Animal-derived foods are traditional sources of B12, whereas most plant-based foods require fortification or microbial biofortification to provide reliable quantities of the vitamin. Food waste provides an important opportunity for vitamin B12 production and recovery. Animal-derived processing residues may contain naturally occurring B12 and could potentially be investigated as direct sources. Plant-based food wastes, however, are more appropriately viewed as substrates for microbial B12 production rather than as direct sources of active B12. This distinction is critical for scientific accuracy.

References

Fang, H., Kang, J., & Zhang, D. (2017). Microbial production of vitamin B12: A review and future perspectives. *Microbial Cell Factories, 16*, 15.

Watanabe, F., Yabuta, Y., Tanioka, Y., & Bito, T. (2013). Biologically active vitamin B12 compounds in foods for preventing deficiency among vegetarians and elderly subjects. *Journal of Agricultural and Food Chemistry, 61*(28), 6769–6775.

Watanabe, F., Yabuta, Y., Bito, T., & Teng, F. (2014). Vitamin B12-containing plant food sources for vegetarians. *Nutrients, 6*(5), 1861–1873.

Torres, M., Sanchis, V., & Ramos, A. J. (2022). Bioprocess strategies for vitamin B12 production by microbial fermentation and its market applications. *Bioengineering, 9*(8), 365.

Martens, J. H., Barg, H., Warren, M. J., & Jahn, D. (2002). Microbial production of vitamin B12. *Applied Microbiology and Biotechnology*, *58*, 275–285.

Ma, H., Wang, L., Zhang, C., & Yi, H. (2008). Biosynthesis, fermentation and application of vitamin B12—A review. *Chinese Journal of Biotechnology, 24*(6), 927–932.

Zhou, Y., He, A., & Xu, B. (2025). Natural resources, quantification, microbial bioconversion, and bioactivities of vitamin B12 for vegetarian diet. *Food Chemistry, 463*, 140849.

Sankar, S., Prajapati, A. V., & Selvaraj, S. (2026). Advances in microbial fermentation of agro-industrial and food waste for sustainable vitamin B12 production. *Cogent Food & Agriculture*, *12*(1).

Sankar, S., Prajapati, A. V., & Selvaraj, S. (2026). Advances in microbial fermentation of agro-industrial and food waste for sustainable vitamin B12 production. *Cogent Food & Agriculture*. DOI: 10.1080/23311932.2026.2642971.

Bio-based vitamin B12: Bridging biotechnology and sustainability for industrial production. (2026). Critical Reviews in Biotechnology.

Vitamin B12: Strategies for enhanced production, fortified functional food products and health benefits. (2023). Process Biochemistry.

Fermentative production of vitamin B12 by Propionibacterium shermanii and Pseudomonas denitrificans and its promising health benefits: A review. (2024).

Vitamin B12 synthesis in sauerkraut juice via Propionibacterium freudenreichii globosum fermentation. (2025). Food and Humanity, 5, 100898.

Enhancement of vitamin B12 in plant-based food through microbial fermentation—a sustainable food system. (2025). Food Chemistry.

Microbial biofortification of fermented foods: A review of probiotic-mediated nutrient enhancement. (2026). Frontiers in Nutrition.

FAO. Food Loss and Food Waste. Food and Agriculture Organization of the United Nations.

FAO. (2011). *Global Food Losses and Food Waste: Extent, Causes and Prevention*. Food and Agriculture Organization of the United Nations.

Volume: 06 Issue No: 09

GREEN MANURING: A NATURE-BASED PATHWAY TO SOIL HEALTH AND SUSTAINABLE CROP PRODUCTION

Article ID: AG-V06-I09-36

***Bommayasamy, N. and Selva Rani, A.**

ICAR-Central Coastal Agricultural Research Institute, Ella, Old Goa, Goa-403402, India

Assistant Professor, Agricultural Research Station, Kovilpatti, Thoothukudi, Tamil Nadu

*Corresponding Author: Bommayasamy, N.

Abstract

Green manuring is an eco-friendly soil management technique that enhances soil fertility, optimises nutrient utilisation, and boosts crop yield by integrating fresh plant biomass. Leguminous green-manure crops like dhaincha, Sesbania rostrata, sun hemp, cowpea, green gram, cluster bean, and pillipesara further enhance soil nitrogen through biological nitrogen fixation. Their integration improves soil organic carbon, aggregation, porosity, water retention, nutrient accessibility, and microbial activity, while diminishing bulk density, erosion, and nutrient depletion. The gradual breakdown of biomass facilitates nutrient mineralisation and recycling, consequently diminishing reliance on mineral fertilizers. The efficacy of biological nitrogen fixation is contingent upon the compatibility between legumes and rhizobia, as well as soil fertility, pH levels, moisture, temperature, and agricultural practices. Therefore, green manuring represents an ecologically beneficial approach to enhancing soil vitality, agricultural yield, and enduring farming sustainability.

Keywords: Biological nitrogen fixation; nutrient use efficiency; soil health; soil organic carbon; sustainable crop production

Introduction

Modern crop production is threatened by declining soil organic matter, nutrient depletion, deteriorating soil structure, and overuse of chemical fertilizers. Intensive cropping, repeated tillage, imbalanced fertilizer use, and inadequate organic residue recycling accelerate soil degradation, reduce nutrient-use efficiency, and lower crop productivity. These concerns

highlight the need to combine biological and organic nutrient-management methods with conventional fertilizer to maintain soil health and sustain agricultural production. Green manuring is an effective, environmentally friendly way to improve soil fertility and crop productivity. Fast-growing crops are grown, and their biomass is added to the soil before flowering or at the appropriate growth stage to enrich organic material and recycle plant nutrients. Leguminous green-manure crops like dhaincha, *Sesbania aculeata*, *Sesbania rostrata*, sunn hemp, cowpea, green gram, cluster bean, and pillipesara are important because they fix atmospheric nitrogen symbiotically with *rhizobia*. They provide in-situ organic matter and biologically fixed nitrogen for subsequent crops.

Biomass incorporation and decomposition gradually release nutrients into the soil, improving synchronization between crop demand and nutrient availability and may reduce mineral nitrogen fertilizer use. Green manuring also enhances soil organic carbon, aggregate stability, porosity, water infiltration and retention, microbial activity, and nutrient cycling. Deep-rooted green-manure crops recycle nutrients from deeper soil layers into the active root zone, reducing nutrient losses. They may also suppress weeds, control erosion, boost soil biological activity, and increase environmental resilience. Thus, green manuring in intensive cropping systems is a sustainable way to improve soil health, nutrient-use efficiency, crop productivity, and the long-term productivity of agricultural soils.

Importance of green manuring

Green manuring is crucial in intensive cropping systems where soil organic carbon and nutrient reserves decline. Mineral fertilizers supply specific nutrients, whereas green manures affect multiple soil properties. Their addition increases organic matter, microbial activity, soil aggregation, nutrient cycling, and biologically fixed nitrogen. Green manuring can improve soil health and partially replace fertilizer N in cereal-based systems, especially rice-based ones. It is used in organic and natural farming, integrated nutrient management, conservation-oriented production systems, and degraded soils needing rebuilt biological activity. Thus, green manures serve multiple purposes:

1. Add fresh organic biomass to soil.
2. Fix and add biological nitrogen.
3. Recycle nutrients from deeper soil layers.
4. Enhance soil organic carbon.

5. Increase soil microbial biomass and enzymatic activity.
6. Improve soil structure, porosity, aeration, and water-holding capacity.
7. Immobilise and recycle nutrients to reduce losses.
8. Suppress weeds through quick ground coverage.
9. Prevent soil erosion and surface crusting.
10. Improve fertilizer efficiency and future crop output.

Criteria for selection of an ideal green manure crop

Green-manure crop effectiveness depends on species selection and suitability to soil, climate, cropping system, and growing period. Green-manure crops should have these traits:

- ✓ Fast germination and establishment.
- ✓ Rapid growth and high biomass accumulation in a short time.
- ✓ Maximum fresh biomass production in favourable conditions.
- ✓ High nitrogen-fixing capacity, especially in legumes.
- ✓ Succulent plant tissues with a low C ratio for fast decomposition.
- ✓ Good performance in low-fertility soil.
- ✓ Effective nutrient scavenging.
- ✓ Strong and extensive root systems.
- ✓ Adaptation to local conditions such as rainfall, temperature, soil reaction, salinity, and waterlogging.
- ✓ Effective ground coverage for weed suppression and erosion control.
- ✓ Minimal seed requirement and ready availability.
- ✓ Low competition for land, water, and time with the main crop.
- ✓ Easy integration with farm machinery.
- ✓ Relief from pests and diseases that could harm future crops.
- ✓ High nutrient concentration in biomass and quick release after incorporation.

The nutrient profile of green-manure biomass varies by species, developmental stage, soil quality, climate conditions, and nutrient management practices. For comparison, commonly reported air-dry values are provided below.

Table 1. Growth duration, biomass production, nutrient content, and key characteristics of major green-manure crops

Green manure Crops	Duration (days)	Biomass (t/ha)	Nutrient content (%)			Major characteristic
			N	P	K	
Dhaincha (*Sesbania aculeata*)	60	23.2	3.50	0.60	1.20	High biomass and N fixation
Sesbania rostrata	50	5.0	2.90	0.30	1.60	Stem and root nodulation; suitable for wet conditions
Sunn hemp (*Crotalaria juncea*)	60	30.6	2.30	0.50	1.80	Rapid growth and high biomass
Cowpea (*Vigna unguiculata)*	60	23.2	1.70	0.28	1.25	Fast ground cover and N fixation
Green gram (*Vigna radiata)*	60	22.5	2.21	0.26	1.26	Short-duration legume
Cluster bean (*Cyamopsis tetragonoloba)*	50	3.2	2.13	0.58	1.17	Suitable for relatively dry conditions
Pillipesara (*Vigna trilobata)*	60	25.0	2.16	0.22	1.10	Adaptable green-manure legume

Green manuring and soil properties

Intensive agriculture, continuous tillage, over-reliance on synthetic fertilisers, and insufficient organic inputs can hasten the loss of soil organic matter and degrade soil aggregates. These changes diminish soil's physical, chemical, and biological characteristics, leading to compaction, inadequate nutrient cycling, reduced biological activity, and lower crop yields. Green manuring offers a biological method for rejuvenating soil vitality through the incorporation of readily decomposable organic matter. Its integration boosts soil organic carbon, aggregate stability, nutrient availability, water retention, and microbial activity, enhancing soil fertility. The breakdown of green-manure residues promotes microbial activity and supports the mineralisation and reuse of vital plant nutrients. Green-manure crops may also help suppress weeds, specific insect pests, and soil-borne ailments, while safeguarding the soil from physical

deterioration. Consequently, incorporating leguminous green manures in intensive cropping systems offers a holistic approach to preserving soil quality, facilitating nutrient cycling, and ensuring sustained agricultural productivity.

Soil physical properties

Continuous integration of green-manure crops enhances soil organic matter and gradually improves physical properties. As biomass decomposes, it releases organic compounds that bind soil particles into stable aggregates, strengthening soil structure. Improved aggregation increases pore volume and water infiltration, percolation, and hydraulic conductivity while reducing runoff and erosion losses. Green manuring also lowers soil bulk density and improves aeration, fostering an optimal environment for root growth and expansion. The resulting increase in soil organic carbon improves water retention and moisture preservation, especially in sandy and arid soils condition. In addition, the robust root systems of green-manure crops like dhaincha and sunn hemp create channels and biopores that improve water flow, aeration, and crop root growth. Together, these improvements bolster soil structural integrity, water retention, root penetration, and resilience to physical deterioration, promoting sustainable agricultural yields.

Soil chemical properties

Green manuring augments soil chemical fertility by increasing organic matter, improving nutrient cycling, and facilitating nutrient utilisation. The integration and breakdown of green biomass emit organic acids and CO_2, helping regulate soil pH and progressively reduce alkalinity. Leguminous green-manure crops enhance soil fertility through biological nitrogen fixation, with species like dhaincha providing a substantial quantity of nutrients when incorporated at flowering. Their extensive root systems absorb nutrients from deeper soil strata and return them to the surface through biomass decomposition, reducing nutrient leaching and losses. Nitrogen released during green-manure mineralisation occurs gradually, better aligning soil nitrogen availability with crop requirements. Organic-matter breakdown also promotes phosphorus solubilization and accessibility through organic acids and altered soil nutrient dynamics. Incorporating green manures with mineral fertilizers enhances soil organic carbon, nutrient accessibility, nutrient-use efficiency, and the enduring fertility of soil and crop yield.

Soil biological properties

Green manuring significantly enhances the biological vitality of soil by providing easily decomposable organic carbon and energy for soil microorganisms. The introduction of fresh

green biomass promotes microbial proliferation, activity, and biomass, thus hastening the breakdown and mineralisation of organic matter. Augmented microbial activity promotes the conversion of organically bound nutrients into forms accessible to plants, thereby enhancing nutrient cycling within the soil-plant ecosystem. Leguminous green manures enhance microbial diversity and advantageous microbial communities, especially when various species are integrated into crop rotations. Increased soil organic matter creates a conducive environment and a sustained energy supply for bacteria, fungi, actinomycetes, and other soil organisms. Increased biological activity also improves soil enzyme function, residue breakdown, nutrient cycling, and aggregate stabilisation. Therefore, continuous green manuring fosters a soil ecosystem that is more biologically active, diverse, and resilient, promoting sustained soil fertility and crop productivity.

Green Manuring on Crop Productivity

Green manuring promotes crop development and yield by augmenting soil organic content, nutrient accessibility, and nutrient utilization efficiency. Leguminous green-manure crops provide a significant amount of biologically fixed nitrogen, which is slowly released during decomposition, better aligning nitrogen availability with crop requirements. The nitrogen from green manure can attain superior agronomic nitrogen-use efficiency compared to mineral nitrogen due to its gradual mineralization and minimised nutrient losses. Among green-manure crops, dhaincha, sunn hemp, cowpea, green gram, cluster bean, and pillipesara have demonstrated considerable advantages for subsequent crops. Dhaincha generates substantial biomass and recycles significant quantities of nitrogen, phosphorus, and potassium, leading to enhanced yield characteristics and grain output of subsequent crops. Green manuring can serve as a partial alternative to mineral fertilizers, enhancing soil organic carbon and nutrient stocks, with residual benefits that may support future crops. Consequently, the incorporation of green manures alongside judicious fertiliser application constitutes a potent approach for improving nutrient-use efficiency, agricultural yield, soil health, and the sustainability of intensive farming systems.

Green manure crops' biological nitrogen fixation

Biological nitrogen fixation constitutes a crucial ecological and agricultural role of leguminous green-manure crops. It signifies a natural mechanism whereby atmospheric molecular nitrogen (N_2), which higher plants cannot directly absorb, is transformed into

biologically accessible nitrogen forms through the actions of specific nitrogen-fixing microorganisms. In leguminous green-manure crops, this mechanism is primarily facilitated by a symbiotic relationship between the plant roots and *rhizobial* bacteria, which encompass species from *Rhizobium*, *Bradyrhizobium*, *Mesorhizobium*, *Ensifer/ Sinorhizobium*, and *Azorhizobium*. Biological nitrogen fixation is thus the primary way green-manure legumes incorporate nitrogen into the soil-plant system, rather than simply reusing nitrogen already in the soil. The process is especially important in low-input, organic, conservation, and climate-smart agricultural systems, as biological nitrogen fixation can partially replace synthetic nitrogen fertilizers while enhancing soil organic matter and biological activity. Leguminous green manure crops obtain a significant amount of their nitrogen from atmospheric N_2. However, the amount fixed can vary considerably by crop species, biomass yield, *rhizobial* efficiency, soil fertility, and environmental factors.

Factors affecting biological nitrogen fixation in green manure crops

The magnitude of biological nitrogen fixation in green manure legumes depends on interactions among plant genotype, rhizobial strain, soil fertility, environmental conditions, and crop management.

- ✓ Successful nodulation requires compatible and efficient *Rhizobium* strains. Seed inoculation is especially beneficial when native rhizobial populations are inadequate.
- ✓ Excessive nitrate or ammonium in soil can suppress nodulation and nitrogenase activity, as legumes preferentially use mineral nitrogen over atmospheric nitrogen.
- ✓ Adequate phosphorus and sulphur support root development, nodulation, and energy-intensive N_2 fixation. Sulphur is necessary for protein synthesis and nodule function.
- ✓ Micronutrients: Molybdenum and iron support nitrogenase activity and electron transfer, while cobalt promotes rhizobial metabolism and effective symbiosis.
- ✓ Soil pH: Moderately acidic to neutral conditions promote rhizobial survival, nutrient availability, nodulation, and efficient N_2 fixation, while extreme acidity or alkalinity can hinder these processes.
- ✓ Proper soil moisture promotes rhizobial infection and nodule activity, while drought reduces photosynthesis and nitrogenase activity. Prolonged waterlogging may also hinder fixation in poorly adapted legumes.

- ✓ Extreme soil temperatures can negatively impact rhizobial survival, nodule development, and nitrogenase activity, with optimal ranges varying between legume-rhizobia associations.
- ✓ Adequate photosynthesis and crop health are crucial for the energy-intensive biological nitrogen fixation process. Factors such as shading, nutrient stress, drought, diseases, and defoliation can significantly reduce N_2 fixation rates.

Conclusion

Green manuring is an effective strategy for improving soil health and crop productivity in intensive cropping systems. Incorporation of green biomass enhances soil organic carbon, aggregation, water retention, nutrient availability, microbial activity, and nutrient cycling. Leguminous green manures additionally enrich soil nitrogen through biological nitrogen fixation, thereby reducing dependence on mineral N fertilizers. Its extensive root systems improve nutrient recycling, soil structure, and resource-use efficiency. Effective green manuring requires appropriate crop selection, efficient legume–rhizobium associations, balanced nutrition, and favourable environmental conditions. Thus, integrating green manures with judicious fertilizer management supports soil fertility, nutrient-use efficiency, crop productivity, and long-term agricultural sustainability.

References

Fageria, N. K. (2007). Green manuring in crop production. *Journal of Plant Nutrition*, 30(5), 691–719.

https://agritech.tnau.ac.in/agriculture/orgfarm_green%20manure.html

Meena, B. L., Fagodiya, R. K., Prajapat, K., Dotaniya, M. L., Kaledhonkar, M. J., Sharma, P. C., Meena, R. S., Mitran, T., & Kumar, S. (2018). Legume green manuring: An option for soil sustainability. In R. S. Meena, A. Das, G. S. Yadav, & R. Lal (Eds.), *Legumes for Soil Health and Sustainable Management* (pp. 387–408). Springer Singapore.

Rani, T.S., Umareddy, R., Ramulu, Ch., Kumar, T.S. (2021). Green manures and green leaf manures for soil fertility improvement: A review. *Journal of Pharmacognosy and Phytochemistry*, *10*(5), 190–196.

Rathika, S., Ramesh, T., Jeyasrinivas, R., Nageswari, R., Satheeshkumar, N., Sanjaykumar, T. 2026. Revitalising soil health through green manuring: A sustainable approach. *Plant Science Today*, *13*(sp5), 1–11.

Volume: 06 Issue No: 09

THE INTERPLAY OF PROCESSING CONDITIONS ON FOOD RHEOLOGY AND TEXTURE: A CRITICAL REVIEW OF KEY FACTORS

Article ID: AG-VO6-I09-37

Mallela Prem Kumar

PhD Scholar, Division of agricultural Engineering at ICAR-IARI, New Delhi-110012, India

Abstract

The rheological properties and ultimate texture of food products are not inherent to their ingredients but are primarily dictated by the processing conditions they undergo. This review synthesizes current knowledge on how three key processing parameters temperature, pressure, and mechanical shear govern the microstructure, rheology, and sensory texture of food systems. The mechanisms by which these factors induce protein denaturation, starch gelatinization, and emulsion or foam stabilization are examined, drawing on foundational and contemporary research (Rao, 2014; Norton & Fryer, 2012; Chen & Rosenthal, 2015; van der Sman & van der Goot, 2020). Individual and combined effects across gels, emulsions, and doughs are critically analyzed, and case studies from post-2018 literature illustrate how these variables act synergistically in real processes such as extrusion, tempering, and homogenization. The central conclusion is that temperature, pressure, and shear are not isolated variables but deeply interconnected levers whose precise control is essential for engineering food products with desired functional and sensory properties.

1. Introduction

1.1 Background. Food rheology, the study of the deformation and flow of food materials under applied forces, provides the critical link between physical chemistry and consumer experience (Rao, 2014). Quantitative measures such as viscosity, elasticity, yield stress, and gel strength correlate directly with sensory texture attributes including hardness, chewiness, spreadability, creaminess, and mouthfeel (Chen & Rosenthal, 2015; Stokes & Frith, 2008). This relationship underpins every stage of food manufacturing, from formulation and process design to quality control and shelf-life stability.

1.2 Problem Statement. Foods are complex multiphase systems of proteins, carbohydrates, lipids, water, and air. Identical ingredient compositions can yield vastly different end products depending solely on processing history: a few degrees of overheating can turn a smooth custard into a curdled mass, while insufficient shear during mixing can leave a cookie crumbly rather than cohesive (Norton & Fryer, 2012). The emergence of novel technologies such as high-pressure processing (HPP), ultrasound, and cold plasma is expanding the range of achievable textures, creating a pressing need to unify existing knowledge into a coherent framework.

1.3 Scope. This review focuses on the individual and synergistic effects of three parameter classes *thermal (temperature), thermodynamic (pressure), and mechanical (shear)* on protein and polysaccharide gels, oil-in-water emulsions, and dough matrices. The discussion follows the causal pathway from processing condition to molecular change, microstructural evolution, macroscopic rheological property, and finally sensory texture perception, illustrated in Figure 1.

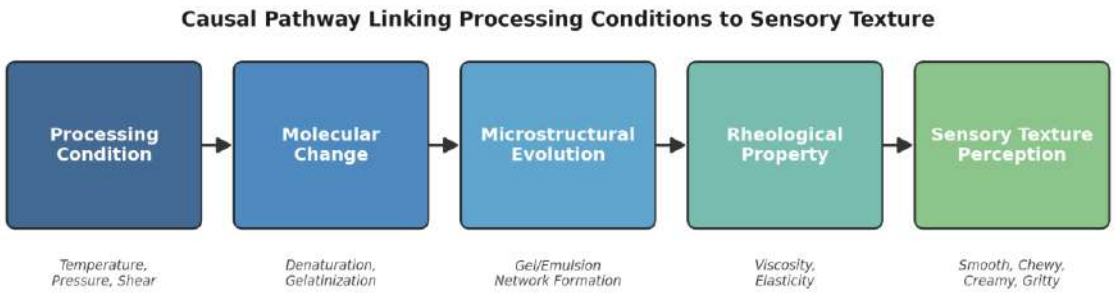


Figure 1. Causal pathway linking processing conditions to sensory texture perception.

2. Theoretical Background of Food Rheology

2.1 Rheological Properties. Viscosity is the internal resistance of a fluid to flow; elasticity is the capacity to store energy and recover original shape; viscoelasticity, the combination of both, is the defining characteristic of most solid and semi-solid foods (Stokes & Frith, 2008). Yield stress and thixotropy describe, respectively, the minimum stress needed to initiate flow and the time-dependent, reversible breakdown of structure under shear.

2.2 Classification of Food Materials. Newtonian fluids (water, syrups, refined oils) have constant viscosity regardless of shear rate. Most foods are non-Newtonian: shear-thinning (ketchup, yogurt, mayonnaise) fluids lose viscosity under shear, which is desirable for pumping and pouring, whereas shear-thickening (concentrated starch suspensions) fluids gain viscosity

under shear. Bingham plastics such as toothpaste behave as solids until a yield stress is exceeded (Rao, 2014).

2.3 Rheology and Microstructure. Macroscopic rheological behavior is a direct consequence of microstructure *the arrangement, volume fraction, and interaction forces of structural components* at the microscale (van der Sman & van der Goot, 2020). The creamy texture of mayonnaise arises from densely packed oil droplets (≥74%) stabilized by lecithin (McClements, 2005); the chewy texture of bread comes from a cross-linked gluten network; the smooth melt of fine chocolate depends on stable Form V cocoa-butter crystals. Processing conditions are the primary tools used to engineer this architecture from a given set of raw ingredients.

3. Impact of Temperature and Pressure

3.1 Temperature Effects on Gels. Heat drives gelation through distinct mechanisms. In starch systems, *gelatinization* is an irreversible, endothermic swelling and disruption of crystalline order that raises viscosity; on cooling, amylose reassociates through *retrogradation*, firming the network (Singh, Dartois, & Kaur, 2010). In proteins, heat causes *denaturation* and unfolding, exposing hydrophobic and sulfhydryl groups that drive aggregation into a gel; heating rate and pH determine whether the result is tender (custard) or rubbery (overcooked egg white) (Foegeding, 2006). Thermoreversible gels such as gelatin instead rely on helix-coil transitions that allow melting on reheating.

3.2 Temperature Effects on Emulsions and Foams. Heating lowers continuous-phase viscosity, accelerating creaming per Stokes' Law, and increases droplet collision frequency, promoting coalescence and Ostwald ripening (McClements, 2005). In fat-based systems like ice cream or whipped cream, temperature governs the crystallization state of fat; melting these crystals destabilizes the structural network.

3.3 High-Pressure Processing (HPP). HPP (100–800 MPa) induces protein gelation at ambient temperature via Le Chatelier's principle, favoring volume-reducing reactions. Unlike heat, pressure primarily disrupts electrostatic and hydrophobic interactions and can rupture disulfide bonds, yielding gels that are typically smoother, glossier, and less rubbery, with finer pore structure and better water-holding capacity (Messens, Van Camp, & Huyghebaert, 1997; Contreras-López et al., 2021). A comparative study on duck egg white gels found pressure-induced gels (400 MPa) to be softer and more elastic than heat-induced gels at 80°C (Xi et al., 2022). Moderate pressures (400–600 MPa) can also induce *cold gelatinization* of starch without

heat, though the resulting pastes often show lower viscosity than heat-gelatinized counterparts (Bauer & Knorr, 2005; Li et al., 2020).

4. Impact of Shear and Mixing

4.1 Shear Rate and Viscosity. Because most foods are shear-thinning, the full flow curve (viscosity versus shear rate), not a single-point measurement, is needed to design pumps, pipelines, and filling lines correctly.

4.2 Dough and Gluten Development. Mixing transforms flour and water into a viscoelastic dough as glutenin and gliadin align and cross-link under shear and extensional forces, forming a gas-retentive network. Under-mixing leaves a weak network; over-mixing ruptures gluten bonds, producing a sticky, weak dough (Cauvain, 2012).

4.3 Homogenization. High-shear homogenization reduces fat droplets from roughly 20 µm to under 1 µm, exponentially increasing interfacial area and emulsifier demand. The result is a large increase in viscosity and markedly improved stability against coalescence and creaming (McClements, 2005; Donsi et al., 2021), fundamental to the mouthfeel of milk, cream, and mayonnaise.

4.4 Extrusion Cooking. Extrusion combines intense shear, high temperature, and high pressure within the barrel to gelatinize starch and denature protein; the sudden pressure drop at the die flashes water to steam, puffing the product. Controlling screw speed, temperature profile, and moisture allows manufacturers to engineer textures ranging from dense meat analogues to light, crispy snacks (Riaz, 2000; Alam et al., 2022; Ozturk & Okur, 2020).

5. Interplay of Parameters on Microstructure and Texture Perception

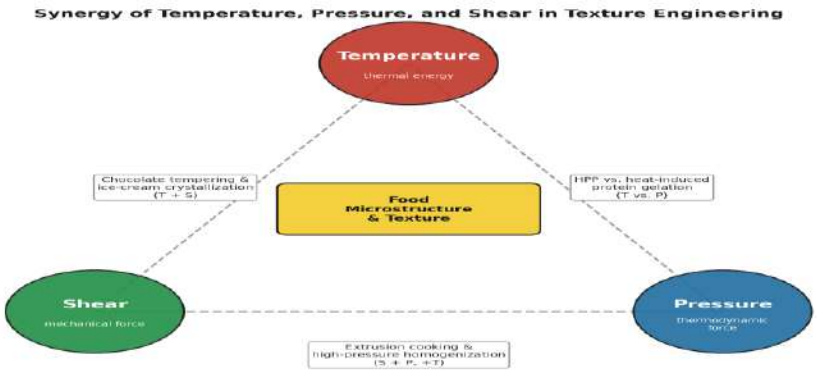


Figure 2 summarizes representative case studies at each pairwise intersection of these parameters.

Temperature, pressure, and shear rarely act in isolation; their synchronized application is often what defines a product's identity. Figure 2 summarizes representative case studies at each pairwise intersection of these parameters.

5.1 Crystallization. In chocolate tempering, precise temperature cycling combined with continuous agitation (shear) promotes small, stable Form V cocoa-butter crystals, giving a clean snap and smooth melt; poor tempering causes fat bloom and graininess (Beckett, 2008). In ice cream, simultaneous rapid cooling and dasher shear in a scraped-surface freezer keep ice crystals small and incorporate air, producing a smooth mouthfeel; insufficient shear yields coarse, icy texture (Goff & Hartel, 2013).

5.2 Aeration. In meringue, whipping (shear) unfolds proteins at the air-water interface to stabilize bubbles, while temperature affects achievable foam volume. In whipped cream, low temperature keeps milk fat partially crystalline so that shear-induced partial coalescence can build a stabilizing fat network; excessive warmth collapses the foam.

5.3 Plant-Based Meat Analogues. Fibrous texturization in extrusion-based meat analogues depends on synchronized heat (protein denaturation), shear (molecular alignment into anisotropic fibers), and controlled moisture and die pressure (structure expansion); insufficient heat gives poor aggregation and insufficient shear gives a crumbly product (Dekkers et al., 2021).

5.4 Sensory Translation. Fine, homogeneous protein or fat-crystal networks with small pores are perceived as smooth and creamy, while coarse, heterogeneous networks read as rubbery, grainy, or icy. Emulsions with small, uniform droplets (from high-pressure homogenization) are perceived as creamy and thick, while coarse emulsions appear watery or oily. Well-developed, cross-linked biopolymer networks are perceived as chewy or elastic (Stokes, 2023; Drapala et al., 2021).

6. Conclusion and Future Directions

Food rheology and texture are not simple consequences of formulation but are meticulously engineered through processing. Temperature, pressure, and shear are deeply interdependent factors that govern protein denaturation, starch gelatinization, fat crystallization, and emulsion or foam stabilization, working additively or antagonistically to build the microstructures that define both functional and sensory properties. Mastering this interplay remains the defining challenge of food process design.

Four directions stand out for future research and industrial practice:

- **Predictive modeling:** multi-scale, mechanistic models (including digital twins and CFD-reaction-kinetics coupling) to forecast texture from composition and process parameters (van der Sman, 2022).
- **Novel processing technologies:** clarifying how cold plasma, pulsed electric fields, and ultrasound modify microstructure and rheology beyond their role in microbial inactivation (Gomez et al., 2021; Soria & Villamiel, 2023).
- **Sustainable and alternative formulations:** understanding how plant proteins and upcycled ingredients respond to thermal, pressure, and shear forces so conventional textures can be replicated in novel matrices (Agarwal et al., 2023; Loveday et al., 2020).
- **In-line and real-time monitoring:** affordable in-line rheometers and AI-driven imaging for closed-loop process control, improving consistency and reducing waste (Khandpur et al., 2022).

Addressing these gaps will move the industry toward a future in which texture is designed with intention rather than left to trial and error.

References

Agarwal, A., et al. (2023). Sustainable processing of plant-based foods: Opportunities and challenges. Trends in Food Science & Technology, 131, 223–236.

Alam, M. S., et al. (2022). Texturization of lentil flour by high-moisture extrusion: The role of mechanical energy input. Journal of Food Engineering, 324, 110987.

Bauer, B. A., & Knorr, D. (2005). The impact of pressure, temperature and treatment time on starches: A review. Innovative Food Science & Emerging Technologies, 6(1), 1–8.

Beckett, S. T. (2008). The Science of Chocolate (2nd ed.). Royal Society of Chemistry.

Cauvain, S. P. (2012). Breadmaking: Improving Quality (2nd ed.). Woodhead Publishing.

Chen, J., & Rosenthal, A. (2015). Food texture and structure. In Modifying Food Texture (pp. 3–24). Woodhead Publishing.

Contreras-López, E., et al. (2021). High-pressure processing on the rheological and structural properties of food. Food Engineering Reviews, 13(3), 622–642.

Dekkers, B. L., et al. (2021). The phase properties of soy protein and wheat gluten in a blend for fibrous structure formation. Food Hydrocolloids, 113, 106493.

Donsi, F., et al. (2021). The role of high-pressure homogenization in the development of plant-based products. Current Opinion in Food Science, 40, 85–92.

Drapala, K. P., et al. (2021). The role of rheology in sensory perception and consumer acceptability of food. In Rheology of Semisolid Foods (pp. 345–372). Springer.

Foegeding, E. A. (2006). Food biophysics of protein gels: A challenge of nano and macroscopic proportions. Food Biophysics, 1(1), 41–50.

Goff, H. D., & Hartel, R. W. (2013). Ice Cream (7th ed.). Springer.

Gomez, M., et al. (2021). Applications of ultrasound in food technology: A review. Ultrasonics Sonochemistry, 70, 105293.

Khandpur, P., et al. (2022). Industry 4.0 in food processing: A systematic review of challenges and opportunities. LWT – Food Science and Technology, 153, 112489.

Li, X., et al. (2020). Impact of high-pressure processing on the structure and properties of starch. Food Chemistry, 318, 126499.

Loveday, S. M., et al. (2020). Food proteins: Technological, nutritional, and sustainability attributes of traditional and emerging proteins. Annual Review of Food Science and Technology, 11, 119–147.

McClements, D. J. (2005). Food Emulsions: Principles, Practices, and Techniques (2nd ed.). CRC Press.

Messens, W., Van Camp, J., & Huyghebaert, A. (1997). The use of high pressure to modify the functionality of food proteins. Trends in Food Science & Technology, 8(4), 107–112.

Norton, J. E., & Fryer, P. J. (2012). Food Processing and Structure Impact on Nutrition and Health. Springer.

Ozturk, O. K., & Okur, M. (2020). Influence of extrusion parameters on the structural properties of breakfast cereals. Journal of Cereal Science, 95, 103052.

Rao, M. A. (2014). Rheology of Fluid and Semisolid Foods: Principles and Applications (2nd ed.). Springer.

Riaz, M. N. (2000). Extruders in Food Applications. CRC Press.

Singh, J., Dartois, A., & Kaur, L. (2010). Starch digestibility in food matrix: A review. Trends in Food Science & Technology, 21(4), 168–180.

Soria, A. C., & Villamiel, M. (2023). Effect of ultrasound on food proteins: A review. Ultrasonics Sonochemistry, 82, 105895.

Stokes, J. R. (2023). Food oral processing and tribology: Relating rheology and texture perception. Annual Review of Food Science and Technology, 14, 5.1–5.22.

Stokes, J. R., & Frith, W. J. (2008). Rheology of industrial and biological materials. Rheologica Acta, 47(7), 693–706.

van der Sman, R. G. M. (2022). Soft matter approaches to structured food. Food & Function, 13(5), 2402–2418.

van der Sman, R. G. M., & van der Goot, A. J. (2020). The science of food structuring. Soft Matter, 16(4), 867–879.

Xi, Y., et al. (2022). Comparative study on the gel properties of duck egg white under high-pressure processing and heat treatment. LWT – Food Science and Technology, 154, 112785.

Volume: 06 Issue No: 09

RABIES PREVENTION AND CONTROL: STRONGER TOGETHER FOR A RABIES-FREE FUTURE

Article ID: AG-VO6-I09-38

***V.Ramakrishna and L.Vimalendran**

Assistant Professor

Tamil Nadu Veterinary and Animal Sciences University – Krishi Vigyan Kendra

Kundrakudi – 630 206, Sivaganga District, Tamil Nadu, India

*Corresponding Author: V.Ramakrishna

Introduction

Rabies is one of the oldest and most feared zoonotic diseases affecting both animals and humans. It is a viral disease that affects the central nervous system and, once clinical signs appear, is virtually 100% fatal. Despite this frightening characteristic, rabies is also one of the most preventable fatal infectious diseases because effective vaccines, appropriate wound management and post-exposure prophylaxis are available. Rabies remains a major public-health problem in more than 150 countries and territories, particularly in Africa and Asia, and approximately 59,000 people are estimated to die from rabies every year. Children are disproportionately affected, and dog bites and scratches account for up to 99% of human rabies cases. Therefore, controlling rabies in dogs is the most important strategy for preventing human rabies (1,2).Every year, **28 September is observed as World Rabies Day** to increase awareness about rabies prevention and promote coordinated action towards elimination of the disease. The date also commemorates the death anniversary of Louis Pasteur, whose pioneering research contributed to the development of the first successful rabies vaccine. The theme for **World Rabies Day 2026 is "Stronger Together."** The theme emphasizes that rabies elimination cannot be achieved by one profession, one department or one organization working alone. Veterinary professionals, doctors, public-health workers, governments, local authorities, animal-welfare organizations, educators, researchers, farmers, pet owners and communities all have important roles in preventing rabies and moving towards a rabies-free future (3).

Rabies as a One Health Disease

Rabies is a classic example of a **One Health disease**, because animal health, human health and environmental factors are closely interconnected. The rabies virus is maintained primarily in animal populations and can be transmitted to humans through the saliva of infected mammals, most commonly following bites or scratches. Dogs remain the principal source of human rabies in many endemic regions. Consequently, protecting people from rabies begins with controlling infection in animal populations, particularly through sustained dog vaccination, responsible animal ownership, surveillance and community participation (1,4).

The One Health concept is particularly important in rural and peri-urban communities where humans, domestic animals, free-roaming dogs and wildlife may come into close contact. Farmers may encounter unfamiliar dogs while working in fields, children may play with community dogs, and pet owners may not always maintain proper vaccination records. Such situations create opportunities for exposure. A well-informed community can greatly reduce this risk by recognizing potentially dangerous animal behaviour, avoiding unnecessary contact with unfamiliar animals and seeking medical attention immediately following a potentially significant exposure.

Why Rabies Continues to Be a Concern

Rabies continues to cause human deaths even though effective vaccines and preventive measures are available. The persistence of the disease is associated with inadequate vaccination coverage among dogs, free-roaming dog populations, delayed reporting of animal bites, inadequate awareness, limited access to post-exposure prophylaxis in some communities and insufficient coordination between animal-health and human-health sectors. In many situations, people may underestimate a minor bite or scratch, believe that a seemingly healthy dog cannot transmit rabies, or depend on traditional remedies instead of seeking medical care. Such delays can have serious consequences because once clinical rabies develops, the disease is almost invariably fatal (1,2).

Children deserve particular attention in rabies-awareness programmes. They may be more likely to approach, play with, tease or handle dogs without understanding the risk. They may also fail to report small scratches or bites to their parents. Children should therefore be taught that unfamiliar animals should not be approached, dogs should not be disturbed while eating or caring for puppies, and every bite or scratch should be reported immediately to a

parent, teacher or responsible adult. Community education is therefore an essential component of rabies prevention (1,5).

Vaccination of Dogs: The First Line of Defence

The most effective way to prevent dog-mediated human rabies is to control the disease at its animal source. **Mass vaccination of dogs** is recognized as one of the most effective and cost-effective strategies for preventing human rabies. Sustaining high vaccination coverage in dog populations reduces the opportunity for the virus to circulate and consequently reduces the risk of transmission to people. International rabies-control programmes have demonstrated that maintaining vaccination coverage of approximately 70% of the dog population in high-risk areas can interrupt transmission (2,4).



Pet owners have an important responsibility in this process. Dogs should receive rabies vaccination according to the schedule recommended by a veterinarian, and vaccination records should be maintained. Puppies should receive vaccination at the appropriate age, followed by booster vaccination as advised by the attending veterinarian. Dogs should also be prevented from roaming unnecessarily, because uncontrolled movement increases the possibility of contact with infected animals and increases the risk of bites and disease transmission.

Community dog vaccination is equally important in areas where free-roaming dogs are common. Vaccinating only owned dogs may leave a large susceptible population capable of maintaining transmission. Therefore, coordinated mass vaccination campaigns involving veterinary authorities, local bodies, trained personnel and community members are essential for

successful rabies control. The focus should be on vaccination, surveillance, responsible dog ownership and humane dog population management rather than indiscriminate killing of dogs, which is not an effective long-term strategy for controlling rabies (1,4).

Responsible Dog Ownership

Responsible dog ownership is an important foundation for rabies prevention. Keeping a dog as a companion animal involves more than providing food and shelter. Owners should ensure regular vaccination, proper veterinary care, adequate nutrition, appropriate housing and responsible control of the animal. Dogs should not be deliberately encouraged to behave aggressively, and children should be taught safe interaction with them. Owners should also seek veterinary advice if their dog develops sudden behavioural changes, unusual aggression, excessive salivation, difficulty swallowing, abnormal vocalization, progressive weakness, paralysis or other unusual neurological signs.

It is important to understand that abnormal behaviour does not automatically mean that an animal has rabies. Several diseases and conditions can produce behavioural or neurological abnormalities. Therefore, members of the public should never attempt to diagnose rabies by handling, restraining or examining a suspicious animal themselves. Veterinary professionals and the appropriate local authorities should be contacted when rabies is suspected.

Recognizing Possible Warning Signs

Rabies can produce a variety of behavioural and neurological abnormalities in animals. Depending on the stage and form of disease, an infected animal may show sudden behavioural changes, unusual aggression, excessive excitement, abnormal vocalization, excessive salivation, difficulty swallowing, wandering behaviour, loss of normal fear, weakness, incoordination or progressive paralysis. Some animals may become unusually aggressive, while others may become quiet, withdrawn or abnormally tame. Because these signs are not specific to rabies, a suspected animal should always be assessed by trained veterinary professionals.

People should avoid approaching animals that are behaving abnormally, especially when there is no obvious reason for the change in behaviour. Children should never attempt to touch, feed, rescue or play with a sick or unusually aggressive animal. If a suspected rabid animal is identified, people should maintain a safe distance and inform the appropriate veterinary or local authority rather than attempting to capture it themselves (4).

What to Do After a Dog Bite or Scratch

One of the most important messages of World Rabies Day is that **every potentially significant animal bite or scratch should be taken seriously**. When a person is bitten or scratched by a potentially rabid animal, the wound should be washed and flushed immediately with soap or detergent and plenty of running water for approximately **15 minutes**. Thorough wound washing is a simple but extremely important first-aid measure because it helps physically remove and inactivate virus at the site of exposure (1,2).

After thorough washing, an appropriate antiseptic may be applied according to medical advice. Harmful traditional substances such as chilli powder, acids, alkalis, plant juices, kerosene or other irritants should not be applied to the wound. Such substances may cause additional tissue injury and do not replace evidence-based rabies prevention. Most importantly, the exposed person should visit a healthcare facility as soon as possible for professional assessment and appropriate post-exposure prophylaxis when indicated (1,2).

Do Not Wait for Symptoms

One of the most dangerous misconceptions about rabies is that treatment is unnecessary if the animal appears healthy immediately after the bite. A person should never make this decision independently. The need for rabies post-exposure prophylaxis must be determined through professional risk assessment based on the nature of the exposure, the animal involved, vaccination status and applicable public-health guidelines. People should also never wait for the development of symptoms in themselves. Rabies prevention is effective when appropriate measures are taken **before clinical disease develops**. Once the virus reaches the central nervous system and clinical symptoms appear, rabies is virtually always fatal. Therefore, immediate action following a potentially infectious exposure is the key to saving life (1).

Post-Exposure Prophylaxis: A Life-Saving Intervention

Post-exposure prophylaxis, commonly known as **PEP**, is the emergency preventive treatment given following a potentially rabies-exposing event. Depending on the category and severity of exposure, PEP may include thorough wound management, rabies vaccination and, when indicated, administration of rabies immunoglobulin or an appropriate alternative according to current guidelines. WHO emphasizes that prompt and appropriate PEP can prevent rabies from progressing to the central nervous system and is highly effective when administered correctly (1).

The exact vaccine schedule and requirement for rabies immunoglobulin depend on the type of exposure and applicable national protocols. Therefore, people should follow the advice of qualified healthcare professionals and should not discontinue a prescribed vaccination schedule on their own. Timely access to quality-assured rabies vaccines and other biologicals is an essential component of rabies elimination programmes.

Role of Veterinarians in Rabies Prevention

Veterinarians are at the frontline of rabies prevention because they work directly with animals and communities. Their responsibilities extend beyond vaccination of individual pets and include mass dog vaccination, investigation of suspected cases, disease surveillance, animal-health education, responsible pet ownership programmes and coordination with public-health authorities. Veterinary professionals can also educate farmers, pet owners and schoolchildren about safe interaction with animals and appropriate action following animal exposure.

Veterinary hospitals, veterinary universities and local authorities can use World Rabies Day as an opportunity to conduct dog vaccination camps, awareness programmes, school education activities, farmer meetings and community outreach programmes. Such activities can be especially valuable in rural and semi-urban areas where awareness and access to preventive services may be limited.

Role of Farmers and Livestock Owners

Farmers and livestock owners also have an important role in rabies prevention. Dogs maintained on farms should be vaccinated regularly and should not be allowed to roam without supervision. Farmers should report unusual animal behaviour and seek veterinary advice if livestock are bitten by dogs or other potentially rabid mammals. People should never attempt to capture or handle a suspected rabid animal without appropriate professional assistance.Rabies is not simply a disease of pet dogs. It affects mammals, including dogs, cats, livestock and wildlife. Therefore, livestock owners, animal handlers and veterinarians should remain alert when animals show unusual neurological or behavioural signs, particularly when there is a history of contact with potentially infected animals (1,4).

Community Awareness: The Key to Prevention

Vaccines and medicines alone cannot eliminate rabies. Community awareness is equally important because people need to understand how rabies is transmitted, how animal bites can be prevented and what action should be taken following exposure. Public-health education should

emphasize that rabies is preventable but becomes virtually fatal after clinical disease develops. This message can encourage people to seek appropriate treatment rather than depending on unproven traditional remedies.

Schools, colleges, veterinary hospitals, primary health centres, panchayats, municipalities, animal-welfare organizations and farmer groups can all participate in rabies-awareness programmes. Posters, public meetings, local-language materials, demonstrations of correct wound washing, vaccination camps, quizzes and social-media campaigns can help reach different sections of society. Children should be given special attention because teaching safe animal behaviour at an early age can prevent risky interactions.

Surveillance and Reporting

Effective surveillance is the foundation of a successful rabies-control programme. Surveillance helps authorities identify areas where rabies occurs, understand animal-bite patterns, monitor vaccination coverage and detect possible outbreaks. Sharing information between veterinary and public-health systems allows authorities to respond rapidly and coordinate preventive measures.

Rabies elimination therefore requires strong communication between veterinary and medical sectors. An animal suspected of rabies should not be considered only a veterinary problem, and a human animal-bite case should not be considered only a medical problem. Both are components of the same transmission chain. This intersectoral collaboration is central to the One Health approach and to the global goal of eliminating human deaths from dog-mediated rabies by 2030 (1,4).

India and Rabies Prevention

India has implemented the **National Rabies Control Programme (NRCP)** to strengthen rabies prevention and control. The programme focuses on improving awareness, strengthening surveillance, supporting appropriate management of animal-bite cases and improving access to anti-rabies vaccine and rabies immunoglobulin. The current NRCP website also provides information regarding first aid after animal bites and availability of facilities providing anti-rabies vaccine and anti-rabies serum. As of August 2026, the programme's dedicated rabies helpline is **15400**, with the service currently covering Andhra Pradesh, Madhya Pradesh, Assam, Puducherry and Delhi. People should use the helpline and local health services according to the current availability in their area (6).

The Indian context highlights the importance of integrating animal vaccination, human post-exposure care, surveillance and public education. Veterinary institutions, local governments, health departments and communities must work together to ensure that dog vaccination programmes reach high-risk areas and that people exposed to potentially rabid animals can obtain appropriate medical care without delay.

World Rabies Day 2026: "Stronger Together"

The theme of **World Rabies Day 2026, "Stronger Together,"** carries a powerful message for India and the rest of the world. Rabies elimination cannot be achieved by veterinarians alone, nor can it be achieved by medical professionals alone. A veterinarian may vaccinate a dog, but the owner must bring the animal for vaccination. A doctor may provide post-exposure treatment, but the exposed person must seek medical care promptly. Government agencies may organize vaccination campaigns, but communities must cooperate with vaccination teams. Teachers may educate children, but parents and communities must reinforce safe animal behaviour (3,4).The theme therefore represents more than a slogan. It represents a practical approach in which different sectors combine their expertise and resources. The global **Zero by 30** strategy seeks to end human deaths from dog-mediated rabies by 2030, and sustained collaboration between animal-health, human-health and community sectors is essential for achieving this goal (4).



Ten Simple Messages for Rabies Prevention

Rabies prevention can be remembered through a few simple messages. Vaccinate dogs regularly and maintain vaccination records. Prevent dogs from roaming unnecessarily. Teach

children never to tease or disturb unfamiliar animals. Never handle a suspected rabid animal. Following a bite or scratch, immediately wash and flush the wound thoroughly with soap and running water for about 15 minutes. Do not apply harmful or irritating substances to the wound. Seek medical attention immediately after a potentially rabies-exposing incident. Follow the prescribed post-exposure vaccination schedule completely. Report suspected rabies cases to veterinary or public-health authorities. Finally, participate in community dog-vaccination and rabies-awareness activities.

Conclusion

Rabies remains one of the world's most serious zoonotic diseases, but it does not have to remain a permanent threat to human society. The scientific knowledge, vaccines and preventive tools required to eliminate dog-mediated human rabies already exist. The challenge is to ensure that these tools are available, accessible and properly implemented in every high-risk community. Vaccination of dogs, responsible animal ownership, appropriate dog population management, public awareness, surveillance, immediate wound washing and timely post-exposure prophylaxis together form the foundation of effective rabies prevention.

World Rabies Day should therefore be more than a one-day awareness event. It should be an opportunity to strengthen year-round action against rabies. Every vaccinated dog reduces the risk of transmission. Every child educated about safe animal behaviour has a better chance of avoiding a dangerous encounter. Every wound washed immediately and every person who receives timely medical assessment represents an opportunity to prevent a fatal disease.

The message of **"Stronger Together"** reminds us that rabies elimination is a shared responsibility. Veterinarians, doctors, farmers, pet owners, teachers, researchers, governments, animal-welfare organizations and communities must work together towards the same goal. By combining animal vaccination, human healthcare, surveillance and community participation, we can break the chain of rabies transmission and move closer to a world where no person dies from dog-mediated rabies.

References

1. World Health Organization. Rabies. Geneva: World Health Organization; 2024.
2. World Health Organization. The facts on rabies. WHO South-East Asia Region. New Delhi: World Health Organization; 2026.

3. World Organisation for Animal Health. World Rabies Day 2026: Stronger Together. Paris: WOAH; 2026.
4. World Organisation for Animal Health. Rabies. Paris: World Organisation for Animal Health; 2026.
5. World Health Organization. Rabies: Key facts and prevention. Geneva: World Health Organization; 2026.
6. Ministry of Health and Family Welfare, Government of India. National Rabies Control Programme (NRCP). National Centre for Disease Control, Government of India; updated 29 August 2026.

Volume: 06 Issue No: 09

FROM CROP RESIDUES TO BIOCHAR: A PATHWAY TO SOIL HEALTH AND CARBON SEQUESTRATION

Article ID: AG-VO6-I09-39

Dr. Priyanka R Khole

Subject Matter Specialist –Agriculture Engineering

SSM's Krishi Vigyan Kendra, Sagroli Nanded II, India

1. Introduction

Agriculture is intrinsically dependent on the quality of natural resources, particularly soil, water, and climate. In India, decades of intensive cultivation, excessive reliance on synthetic fertilizers, frequent soil disturbance, and indiscriminate burning or disposal of crop residues have accelerated the depletion of Soil Organic Carbon (SOC), resulting in declining soil fertility and ecosystem resilience. The reduction in SOC adversely affects soil structure, aggregate stability, nutrient cycling, microbial diversity, water retention, and crop productivity. Furthermore, the loss of soil carbon contributes significantly to greenhouse gas (GHG) emissions, thereby intensifying climate change.

The restoration of soil organic carbon has therefore become a central objective of climate-smart agriculture, regenerative agriculture, and sustainable land management. Among the various carbon management strategies, biochar has gained global recognition as a promising technology capable of simultaneously improving soil health, enhancing agricultural productivity, recycling agricultural biomass, and providing long-term carbon sequestration. Recent reviews have identified biochar as one of the most effective nature-based solutions for sustainable agriculture and greenhouse gas mitigation. (Frontiers)

Biochar is a stable, carbon-rich material produced by the **thermal decomposition of organic materials** such as agricultural residues, wood, and biomass in a **low-oxygen environment** through the **pyrolysis process**. **Typical Pyrolysis Temperature: 300–600°C**.

Biochar is a **carbon-rich, porous, and highly recalcitrant material** produced through the thermochemical conversion of biomass under oxygen-limited conditions, a process known as

pyrolysis. Feedstocks commonly used for biochar production include crop residues, woody biomass, grasses, animal manure, agro-industrial wastes, and other lignocellulosic materials.

Unlike complete combustion, pyrolysis converts unstable organic carbon into **aromatic carbon structures** that are highly resistant to microbial decomposition. Consequently, a substantial fraction of the carbon contained in biomass is stabilized and retained in soils for decades to centuries, making biochar an effective tool for **long-term carbon sequestration**. The physicochemical properties of biochar—including surface area, pore structure, pH, ash content, and nutrient composition—are influenced by the feedstock characteristics and pyrolysis conditions, particularly temperature and residence time.

2. Organic Sources Suitable for Biochar Production

Almost any **organic biomass** can be converted into biochar through the **pyrolysis process**.

Sr. No.	Category	Organic Material
1	**Agricultural Residues**	Cotton stalk / Pigeon pea stalk
2		Corn cob
3		Corn stalk
4		Wheat straw
5		Rice straw
6		Pearl millet stalk
7		Mustard stalk
8		Soybean stalk
9		Sugar beet tailings
10	**Forest Residues**	Sawdust
11		Wood residues
12	**Agro-Industrial Waste**	Paper mill waste
13		Jatropha husk
14		Coffee husk
15		Coconut shell
16		Cocoa pod husk

3. Biochar Production Technologies

Biochar can be produced from a wide range of agricultural, forestry, and agro-industrial biomass residues using different **pyrolysis technologies**. The selection of a production method depends on the **availability and type of biomass, required production capacity, investment cost, ease of operation, and local conditions**. For small and marginal farmers, low-cost methods such as the **pit, Kon Tikki, drum, and box methods** can be useful for converting crop residues into biochar at the farm or community level. For larger-scale and continuous production, **semi-automatic and automatic biochar-making machines** can provide better control over the pyrolysis process, temperature, production capacity, and quality of biochar.

1. **Pit Method** – Biochar production through the pit method
2. **Kon Tikki Method** – Biochar production using the Kon Tikki method
3. **Drum Method** – Biochar production using a drum kiln
4. **Box Method** – Biochar production using a low-cost biochar production box
5. **Semi-Automatic and automatic biochar making Machine** – Biochar production using an automatic biochar-making machine.

4. Mechanisms Through Which Biochar Improves Soil Health

The beneficial effects of biochar arise from its distinctive physical, chemical, and biological properties.

Physical improvements include enhanced soil aggregation, reduced bulk density, increased porosity, improved infiltration, and greater water-holding capacity. These characteristics improve root growth and increase drought resilience.

Chemical improvements include increased cation exchange capacity (CEC), improved nutrient retention, reduced nutrient leaching, pH buffering in acidic soils, and greater fertilizer-use efficiency.

Biological improvements occur because the porous matrix of biochar provides protected microhabitats for beneficial microorganisms, including bacteria, fungi, and mycorrhizae. Enhanced microbial activity stimulates nutrient mineralization, organic matter stabilization, and overall soil biological functioning.

Collectively, these improvements contribute to increased soil fertility, improved nutrient cycling, and enhanced crop productivity under diverse agroecological conditions.

5. **Benefits of Biochar**

Benefit	Description
1. Improves Soil Fertility	Biochar has a porous structure that provides a favorable habitat for beneficial microorganisms and enhances biological activity in the soil. It can also improve nutrient and organic matter retention.
2. Increases Water-Holding Capacity	Biochar improves the soil's ability to absorb and retain water, which can help conserve irrigation water, particularly in dryland areas.
3. Helps Mitigate Climate Change	Biochar stores carbon in a stable form for a long period, thereby reducing the amount of carbon returning to the atmosphere as CO_2.
4. Enhances the Efficiency of Organic Manures	Biochar can retain nutrients and improve the effectiveness of compost and other organic manures when applied in combination with them.
5. Improves Crop Productivity	Appropriate use of biochar can improve soil conditions, nutrient availability and water management, potentially contributing to higher crop yields.
6. Long-Term Carbon Sequestration	Biochar converts part of the carbon present in biomass into a relatively stable form that can remain stored in soil for a long period. This contributes to **carbon sequestration** and helps in climate-change mitigation.

6. Methods of Biochar Application and Use

Application Method	Use of Biochar
1. Surface Broadcasting and Incorporation	Biochar is uniformly spread over the soil surface and incorporated into the soil using a cultivator, rotavator or other suitable tillage equipment.
2. Banding or Trench Application	Biochar is placed in bands along the crop rows or in trenches near the root zone, allowing nutrients and moisture to remain available around the plants.

3. Blending Biochar with Compost or Fertilizers	Biochar can be mixed with compost, farmyard manure or suitable fertilizers before application. This helps improve nutrient retention and the efficiency of organic inputs.
4. Mixing Biochar into Potting Media	Biochar can be mixed with soil, compost and other growing media for nursery plants, vegetables, horticultural crops and container-grown plants.
5. Integration into Manure Management Systems	Biochar can be added to livestock manure, bedding or manure-storage systems to help retain nutrients, reduce nutrient losses and improve the quality of the resulting manure or compost.
6. Biochar Slurry or Liquid Application	Fine biochar can be mixed with water, compost slurry or other suitable organic inputs and applied to the soil or around the root zone. This method can facilitate uniform application of fine biochar particles.

7. Biochar as a Carbon Sequestration Technology

Biochar represents one of the most promising **Carbon Dioxide Removal (CDR)** technologies in agriculture. During photosynthesis, plants assimilate atmospheric carbon dioxide into biomass. Through pyrolysis, a considerable proportion of this biogenic carbon is converted into chemically stable aromatic carbon rather than being rapidly returned to the atmosphere through decomposition.

When incorporated into agricultural soils, biochar acts as a persistent carbon sink with mean residence times ranging from several decades to hundreds or even thousands of years, depending on soil type, climate, and biochar properties. In addition to direct carbon storage, biochar can reduce emissions of methane (CH_4) and nitrous oxide (N_2O), thereby contributing to lower agricultural greenhouse gas emissions and supporting national and global climate mitigation strategies.

8. Future Perspectives

Growing global interest in **carbon farming**, **nature-based climate solutions**, and **carbon credit markets** has positioned biochar as a strategic technology for achieving agricultural sustainability and climate mitigation simultaneously. Current research focuses on optimizing feedstock selection, pyrolysis technologies, biochar engineering, nutrient-enriched

biochar formulations, and the integration of biochar with compost, microbial inoculants, and precision nutrient management. These innovations are expected to enhance both agronomic performance and the carbon sequestration potential of biochar across diverse farming system

Conclusion

Biochar represents a scientifically validated and environmentally sustainable soil amendment that addresses multiple agricultural and environmental challenges simultaneously. By improving soil physical, chemical, and biological properties while providing long-term carbon sequestration, biochar supports enhanced crop productivity, efficient resource recycling, and climate resilience. Within Integrated Farming Systems, it transforms agricultural biomass into a valuable resource, promotes circular nutrient management, and contributes to sustainable agricultural development. Consequently, biochar should be recognized as a key component of future climate-smart farming systems and soil carbon restoration strategies.

Volume: 06 Issue No: 09

INCIDENCE OF BROWN PLANT HOPPER AND ITS MANAGEMENT IN PADDY

Article ID: AG-V06-I09-40

***Y.Swathi and K.Bhavya**

Regional Agricultural Research Station, Jagtial, PJTSAU, Telangana, India

*Corresponding Author: Y.Swathi

Introduction

Rice is the staple food of India. While rice production has so far kept in pace with population increase, future demand for the growing population can be met with strong research support aimed at enhancing rice productivity and sustaining the production. Among the biotic stresses that limit the production, insect pests rank second to weeds. Understanding bio-ecology of the key insect pests forms the basis of developing strategies to regulate their populations. Despite over 100 species of insects being reported to feed on rice, about 6 major and an equal number of minor pests are of economic importance.

In India, Present the paddy crop is at panicle initiation to grain filling stage. The major pests namely plant hoppers and panicle mite are attacking the crop and causing economic yield loss.

Plant Hoppers:

Rice plant hoppers are major pests across the country especially in irrigated rice where intensive rice cropping is being done. Three species of plant hoppers reported on rice are:

1. Brown plant hopper (BPH), *Nilaparvata lugens*
2. White backed plant hopper (WBPH), *Sogatella furcifera* (Horvath) and
3. Smaller brown plant hopper (SBPH), *Laodelphax striatellus* Fallén.

First two of these are of economic importance. Besides direct damage to the crop, BPH and SBPH also transmit viral diseases like rice grassy stunt, rice ragged stunt, and yellowing syndrome. The plant hoppers suck the plant sap from the phloem vessels through their proboscis. Due to this, plant starts wilting with outer most leaves drying first and then the entire plant dries

up – a symptom often called “Hopper burn”.

Nature of Damage: Plant hoppers generally appear in the field about one month after transplanting in normal or early planted fields. However, in late planted crop adults may move from already planted crop to young crop much earlier. Pest population builds up faster after the crop leaf canopy covers the open space between the plants. This can happen early if the plant spacing is closer and higher dose of nitrogen fertilizer is used for top dressing. Population builds up is further facilitated with the use of broad spectrum or ineffective insecticides early in the season due to elimination of natural bio control agents like predators and parasitoids. Plant hoppers initially immigrate and settle down randomly on young plants. These immigrant macropterous forms produce first generation brachypterous forms in 3-4 weeks time. When these adults produce a large second-generation nymph, both adults and nymphs feed voraciously on the plant. This results in the early symptom of yellowing in patches in the field.

Symptoms of Damage:

- Hopper burn or yellowing, browning and drying of plant
- Circular patches of drying and lodging of matured plant
- Nymphs and adults congregate at the base of the plant above the water level
- Affected plant dries up and gives a scorched appearance called “ hopper burn”
- It is vector of grassy stunt, ragged stunt and wilted stunt diseases
- Hopper burn caused by the plant hopper is distinguished from other hopper burn symptom by the presence of visible sooty molds at the bases of the rice plant. Virus infected plant may also be found.

	
Adults suck the spa from plant stem tissues	Hopper burn in circular fashion

	
Adults of brown plant hopper	Complete hopper burn symptoms

MANAGEMENT

Mechanical & physical measures:

- ✓ Flood the seedbed, for a day, so that only the tips of seedlings are exposed will control BPH.
- ✓ Sweep small seedbeds with a net to remove some BPH (but not eggs), particularly from dry seed beds. At high BPH densities, sweeping will not remove sufficient numbers of BPH from the base of the plant.
- ✓ Alternate wetting and drying
- ✓ Application of fertilizers in recommended doses only

Biological control

- ✓ If natural enemies out-number BPH the risk of hopper burn is low. Even rice already damaged by hopper burn should not be treated with insecticides if natural enemies out-number BPH.
- ✓ Natural enemies of BPH include water striders, mirid bugs, spiders, and various egg parasitoids.

Chemical control

- Only apply insecticides to the seedbed, for BPH or WBPH above ETL like 10-15 hopers/hill at vegetative stage and 20-25 hoppers/hill at reproductive stage.
- Spraying of Acephate 1.5gr/li or incidence is severe spraying of Dinotefuran 0.4g/li or buprofezin 1.6ml/li or tryflumzopyram 0.48 ml/li
- Do not apply the synthetic pyrethroids like cypermethrin or deltamethrin or combinations like profenophos + cypermethrin, they act as synergist.

Volume: 06 Issue No: 09

GROWING FENNEL FOR MORE INCOME- A SUCCESS STORY

Article ID: AG-V06-I09-41

***Raj Kumar[1], N. K. Singh[1], Sushil Kumar[2] and A.K. Rai[3]**

[1]KVK, ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan (ICAR-VPKAS), Bageshwar

[2] ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan (ICAR-VPKAS), Almora, India

[3]KVK, ICAR-National Rice Research Institute (ICAR-NRRI), Koderma, India

*Corresponding Author: Raj Kumar

Introduction

Sh. Rathav Rameshbhai G. is 10th pass and resident of village – Pandyapura, Taluka- Godhra, Dist –Panchmahal, Gujarat. He is having 4.25 ha land (2 ha irrigated and 2.25 ha rainfed). He grows paddy, maize, pigeon pea, castor, fennel, etc with traditional system. He was not satisfied with the income earned from agriculture. The climatic conditions of the area are characterized as hot semi arid. The annual rainfall is mainly confined in the monsoon period (July- September) and actual mean precipitation is about 670-830 mm and the total number of rainy days 33.50-37.36. The mean annual maximum and minimum temperatures vary from 42-46°C (May) and 6-8.6°C (January), respectively. The soil depth ranged from 0.92 to 1.35 m derived from mixed alluvial basalt, quartzite, granite and layers of limestone. The depth of available ground water is 45-60 feet. The soil of his farm is black to loamy sand with available N (135.50-148.50 kg/ha), P (6.40-8.20 kg/ha) and K (141.20-145.30kg/ha), organic carbon (0.33%), EC (0.13-0.18 dSm^{-1}) and pH (8.10). The quality of the ground water is medium good.

Plan implement and support:

He came at KVK in various programs like as training, meeting, campaigns regularly to solve his problem related to agriculture and allied sectors. He was selected as front line demonstration (FLD) on fennel. The ten farmers of various villages of the district were selected and distributed seeds. Before implementation of FLD a training programme was conducted and to trained the framers about all important aspects of fennel cultivation. The seed of fennel cv.

Ajmer Fennel-1 was procured from National Research Centre on Seed spices, Ajmer. The seeds are sown in well prepared nursery beds. The 3-4 week old seedlings were transplanted in the field at the distance of 75 x 60cm. All the package and practices were adopted as per suggestion of KVK experts. KVK experts visited demonstration field frequently from preparation of land, layout, planting, application of manure and fertilizers weed management, harvesting, grading and sale of produce. The various programs *viz*. training, field day, advisory service, telephonic advisory, deliver lectures, field visit, were carried out by KVK for at horizontal dissemination of the technology.



Sowing of seed in nursery bed



Flowering stage



Harvesting of umbels



Drying of umbels

Output:

After successful compilations of the crop, he got highest yield. The data on growth and yield of Ajmer Fennel-1 and local check are given in Table-1. Both improved technology Fennel cv. Ajmer Fennel-1 and local check was planted at 75 x 60 cm distance, commencement of flowering (46-50 and 50-55 DAS), No of umbels /plant (10-12 and 8-10), plant height (143 and

1.28m), harvesting (3rd and 4th week of January) and yield (14.25 and 10.50q/ha) were recorded, respectively.

Table-1 Growth and yield parameters of fennel cultivation

Parameters	Ajmer Fennel-1	Local Check
Plating distance (cm)	**75x60**	**75x60**
Date of transplanting	4rd week of September	4rd week of September
Commencement of flowering (DOT)	46-50	50-55
No of umbels /plant	10-12	8-10
Plant height (m)	1.43	1.28
Harvesting	3rd week of March	4rd week of March
Yield (q/ha)	14.25	**10.50**

Table -2 revels that the cost of cultivation (₹ 22500), gross return (₹78375), net return (₹55875) and cost benefit ratio (3.48) was recorded in improved technology (Ajmer Fennel-1) while in local check ₹ 20500, ₹ 57750, ₹ 37250 and 2.81, respectively.

Table 2 Economics of cultivation of fennel cv. Ajmer Fennel-1 and Local Check

Variety	Cost of cultivation (₹/ ha)	Gross return (₹/ ha)	Net return (₹/ ha)	B: C ratio
Ajmer Fennel-1	22500	78375	55875	3.48
Local Check	20500	57750	37250	2.81

Impact:

Now he is become a key farmer for vegetable cultivation especially fennel and advised to the other farmers of the district about improved cultivation of vegetable for more income. Now innovative farmers of the area are adopting this simple and profitable technology. The horizontal dissemination of this technology increased day by day and more than 140 farmers of the district are adopting this technology. Halol and kalol talukas of the Panchmahal district are dominating in fennel cultivation than other others.

Volume: 06 Issue No: 09

CRISPR – Cas9: AS A NEW TECHNIQUE IN CROP IMPROVEMENT

Article ID: AG-V06-I09-42

***Harshitha Elangovan [1] and Dr. Andrew Peter Leon [2]**

[1]UG Student B.Sc.(Hons.) Agriculture, S Thangapazham Agricultural College, Tenkasi

[2]Assistant Professor, Genetics and Plant Breeding, S Thangapazham Agricultural College, Tenkasi, Tamil Nadu, India

*Corresponding Author : Harshitha Elangovan

Abstract

CRISPR-Cas9 has revolutionized plant breeding by providing a precise, efficient, and cost-effective genome-editing tool for crop improvement. Unlike conventional breeding methods, which are time-consuming and dependent on natural genetic variation, CRISPR-Cas9 enables targeted modification of specific genes to develop improved crop varieties within a shorter period. This technology has been successfully applied to enhance yield, nutritional quality, disease resistance, and tolerance to abiotic stresses such as drought and salinity in major field and vegetable crops. It has also facilitated improvements in fruit quality, shelf life, and plant architecture, thereby contributing to sustainable agricultural production and global food security. Continuous research aimed at improving editing accuracy and developing advanced genome-editing systems is expected to further expand its applications. Overall, CRISPR-Cas9 represents a transformative technology and offers promising opportunities to address future agricultural challenges under changing climatic conditions.

Introduction

The global demand for food is increasing rapidly due to population growth, climate change, shrinking arable land, and the emergence of new pests and diseases. Conventional plant breeding has played a significant role in improving crop productivity; however, it is often slow, labor-intensive, and dependent on naturally occurring genetic variation. Modern agriculture therefore requires innovative technologies capable of producing improved crop varieties with

greater speed and precision. Among these technologies, **CRISPR-Cas9 (Clustered Regularly Interspaced Short Palindromic Repeats-associated protein 9)** has emerged as one of the most revolutionary genome-editing tools in plant science. It enables scientists to modify specific genes with remarkable accuracy, making crop improvement faster, more efficient, and cost-effective. The technology has transformed plant breeding by facilitating the development of crops with improved yield, nutritional quality, resistance to diseases, tolerance to abiotic stresses, and enhanced adaptability to changing environmental conditions.



Evolution of CRISPR-Cas9

Found in bacteria by adaptive response to bacteriophage as an immune defence which was a naturally occuring genome editing system. Scientists later discovered that this defense mechanism could be adapted as a programmable genome-editing tool. In 2012, CRISPR-Cas9 was successfully developed for precise gene editing, and by 2013 it was being applied in plants. Compared with earlier genome-editing technologies such as Zinc Finger Nucleases (ZFNs) and TALENs, CRISPR-Cas9 is simpler to design, more efficient, less expensive, and highly versatile.

Mechanism of CRISPR-Cas9

The CRISPR-Cas9 genome-editing system functions through a series of coordinated molecular events that enable precise modification of a target gene. It primarily consists of two essential components: the **Cas9 nuclease**, which acts as molecular scissors to cut DNA, and a **single-guide RNA (sgRNA)**, which directs Cas9 to the desired DNA sequence. Once introduced into the plant cell, these components work together to identify, cleave, and modify the target gene. The steps involved in the mechanism are

1. Selection of the Target Gene

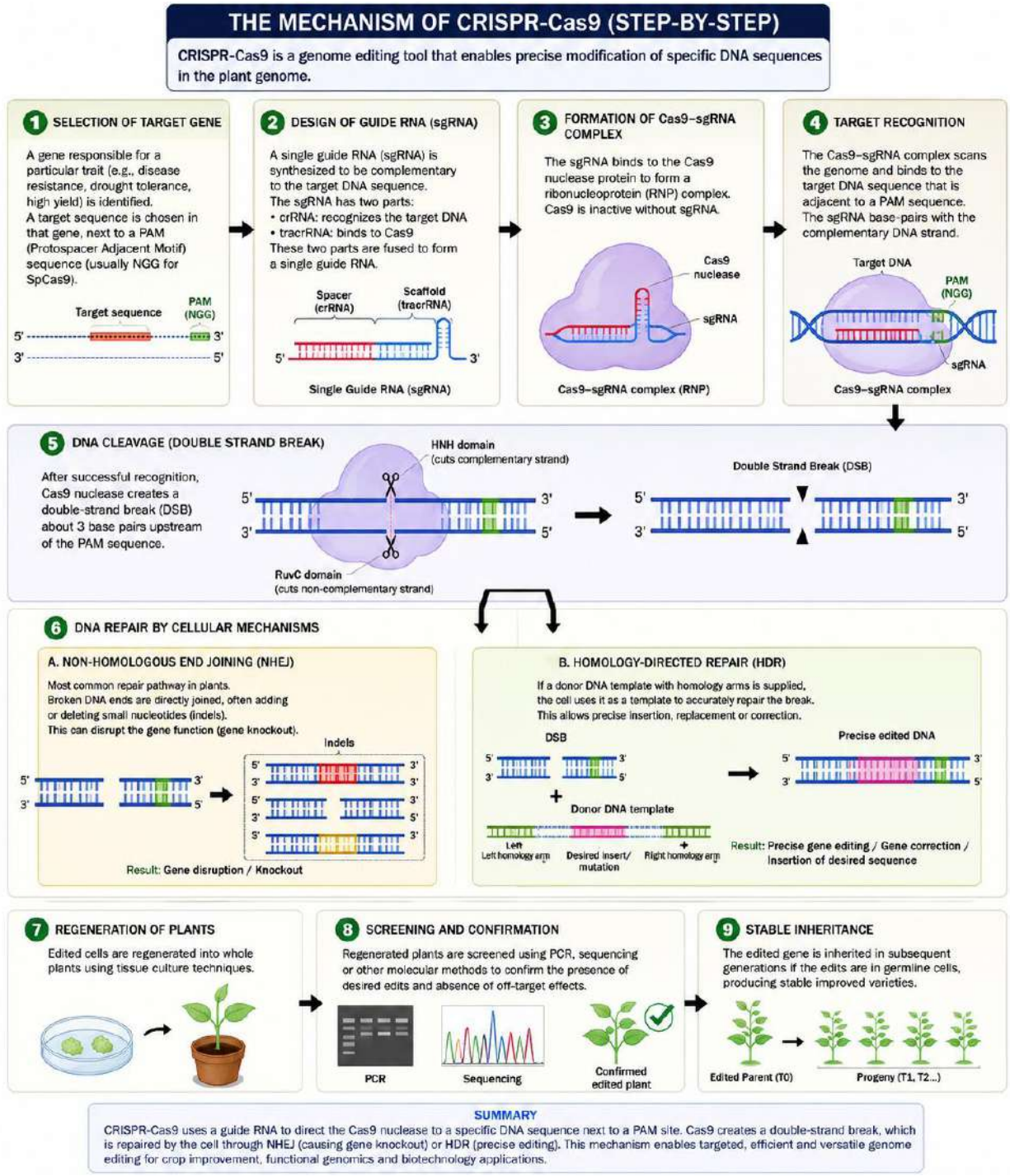
2. Design of Single-Guide RNA (sgRNA)

3. Formation of the Cas9-sgRNA Complex

4. DNA Recognition and Cleavage

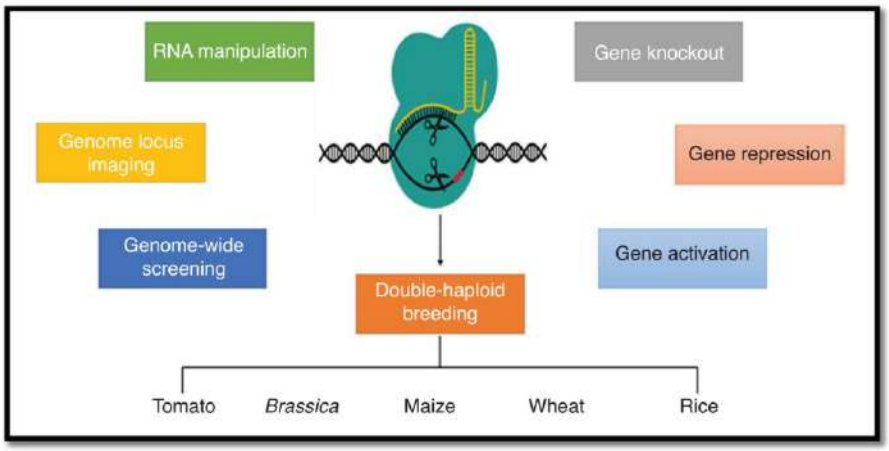
5. DNA Repair Mechanisms

6. Regeneration and Screening of Edited Plants



APPLICATION IN CROP IMPROVEMENT

- In **rice**, CRISPR technology has been used to improve grain quality and resistance to environmental stresses**.**
- **Wheat** breeding has benefited from genome editing for disease resistance and yield improvement.
- In tomato, genome editing has been applied to regulate fruit ripening, enhance fruit quality, modify plant architecture, and increase resistance to diseases.
- In cucumber, researchers have improved tolerance to salinity and diseases.
- Eggplant has been genetically modified to enhance resistance against pathogens and improve agronomic performance
- Similar progress has been reported in maize, soybean, apple, and several other economically important crops



INDIAN GOVERNMENT'S REVIEW ON CRISPR-CAS9

1. **Government Support**
    - The Government of India recognizes **CRISPR-Cas9** as an important genome-editing technology with applications in agriculture, medicine, and biotechnology.
    - Research is supported by the **Department of Biotechnology (DBT)**, **ICAR**, **CSIR**, and **ICMR**.
2. **Regulatory Framework**
    - In 2022, India notified the **Guidelines for the Safety Assessment of Genome Edited Plants**.

- Genome-edited plants developed through **SDN-1** and **SDN-2** methods (without introducing foreign DNA) are regulated differently from conventional GM crops, with specific Standard Operating Procedures (SOPs) for regulatory review.

3. **Agricultural Applications**
   - CRISPR-Cas9 is being used to develop crop varieties with:
     - Higher yield
     - Drought tolerance
     - Salinity tolerance
     - Disease and pest resistance
     - Improved nutritional quality
   - ICAR has developed gene-edited rice varieties using genome-editing approaches.
4. **Medical Applications**
   - India supports research on CRISPR-based gene therapies under national guidelines for gene therapy.
   - Clinical research is progressing under strict ethical and regulatory oversight by agencies such as DBT, ICMR, and CDSCO.

VARIETY RELEASED IN INDIA

DRR Dhan 100 (Rice)

- **Institution:** Indian Council of Agricultural Research (ICAR) – Indian Institute of Rice Research (IIRR)
- **Technology:** CRISPR-Cas9 genome editing
- **Trait:** Improved drought tolerance and higher yield
- **Significance:** One of India's first genome-edited rice varieties released for cultivation

Pusa DST Rice 1

- **Institution:** Indian Agricultural Research Institute (IARI)
- **Technology:** CRISPR-Cas9 (genome editing)
- **Trait:** Drought and climate resilience
- **Benefit:** Better performance under water-limited conditions.

3. Kamala (Genome-edited Rice)

- **Institution:** Indian Agricultural Research Institute (IARI)
- **Technology:** CRISPR-based genome editing

- **Trait:** Improved yield and adaptability

POPULAR VARIETIES RELEASED

VARIETY	CROP	COUNTRY	IMPROVED TRAIT
Pusa DST Rice 1	Rice	India	Drought, salinity and alkalinity tolerance
DRR Dhan 100 (Kamala	Rice	India	Higher yield, early maturity, improved nitrogen-use efficiency
Sicilian Rouge High GABA	Tomato	Japan	High GABA content (health-promoting tomato); first commercial CRISPR food crop
Waxy Corn	Maize	USA	High amylopectin starch for food processing
Non-browning Mushroom	Mushroom	USA	Delayed browning and longer shelf life
High Oleic Soybean	Soybean	USA	Healthier edible oil with high oleic acid
Non-browning Banana	Banana	Philippines	Reduced browning and longer shelf life

Conclusion

CRISPR-Cas9 has emerged as one of the most transformative technologies in modern plant breeding, offering an efficient, precise, and cost-effective approach for crop improvement. Unlike conventional breeding methods, it enables targeted modification of specific genes, significantly reducing the time required to develop improved crop varieties. The technology has been successfully applied to enhance yield, nutritional quality, disease resistance, herbicide tolerance, and resilience to abiotic stresses such as drought and salinity in both field and vegetable crops. Recent advances, including base editing, prime editing, and multiplex genome editing, have further expanded its potential for precise genetic improvement.

Future Breakthrough

Despite its remarkable advantages, challenges such as off-target effects, efficient delivery of genome-editing components, biosafety concerns, public acceptance, and varying regulatory policies continue to influence its widespread adoption. Continued research aimed at improving editing accuracy, developing transgene-free editing methods, and establishing clear regulatory frameworks will be essential for realizing the full potential of this technology.

Overall, CRISPR-Cas9 represents a major breakthrough in agricultural biotechnology and is expected to play a crucial role in developing climate-resilient, high-yielding, and nutritionally enhanced crops. Its responsible application will contribute significantly to sustainable agriculture, global food security, and meeting the challenges of a growing population under changing climatic conditions.

Volume: 06 Issue No: 09

PLANT GROWTH REGULATORS: SMALL MOLECULES WITH BIG EFFECTS ON CROP PRODUCTION

Article ID: AG-V06-I09-43

Lakshmi S

Department of Crop Physiology, Adhiparasakthi Horticultural College, G.B. Nagar, Kalavai – 632506, Ranipet District, Tamil Nadu, India

Abstract

Plant Growth Regulators (PGRs) are powerful tools for modifying crop growth, development and responses to environmental stress. Auxins promote rooting and fruit retention, gibberellins stimulate germination, elongation and fruit development, while cytokinins delay senescence and help maintain photosynthetic activity. Abscisic acid regulates water conservation and stress responses, whereas ethylene has major roles in fruit ripening and senescence. Emerging regulators such as brassinosteroids, jasmonates, salicylic acid and strigolactones further expand opportunities for crop management. Their applications can improve establishment, root growth, flowering, fruit set, yield and quality, and may strengthen crop tolerance to drought, heat and salinity. Precision spraying and improved formulations could increase application efficiency. However, crop-specific responses, concentration, timing, environmental conditions and regulatory requirements must be considered for safe and effective use. Judicious application of PGRs can contribute to productive and climate-resilient agriculture.

Keywords: auxins; gibberellins; cytokinins; stress tolerance; crop productivity; plant hormones

Introduction

Modern agriculture must maintain productivity despite climate change, declining soil fertility, water scarcity and increasing food demand. Plant Growth Regulators (PGRs) provide one useful tool because they can modify plant physiological processes at very low concentrations. Unlike fertilizers, which supply nutrients, PGRs influence processes such as growth, flowering, fruiting, ripening and stress responses. Their judicious use can therefore support crop productivity, quality and resilience.

PGRs may be naturally produced by plants or synthesized for agricultural use. The major classical groups are auxins, gibberellins, cytokinins, abscisic acid (ABA) and ethylene. Brassinosteroids, jasmonates, salicylic acid and strigolactones are also recognized as important signaling molecules involved in growth, development and stress adaptation.[2]

What are Plant Growth Regulators?

Plant Growth Regulators are organic compounds that influence physiological activities at very low concentrations. Their effects depend on the type of regulator, concentration, crop, developmental stage and environmental conditions. Rather than acting independently, different regulators interact with one another to coordinate plant responses throughout the crop life cycle.

Auxins: Regulators of Growth and Root Development

Auxins, including the natural hormone indole-3-acetic acid, are central to cell elongation, root initiation, vascular differentiation and apical dominance. In crop production, auxin-based products are used to promote rooting in cuttings and transplants, reduce premature fruit drop, improve fruit set and induce parthenocarpic fruit development. Their use has been reported in crops such as tomato, mango, citrus and grapes.[3]

Gibberellins: Promoters of Growth and Fruit Development

Gibberellins regulate seed germination, stem elongation, flowering and fruit development. Gibberellic acid (GA_3) is widely used to break dormancy, improve germination, increase vegetative growth, enhance fruit size and promote uniform flowering. In grapes, GA_3 is commonly used to increase berry size and improve bunch quality, while applications in other crops can support growth and marketable yield.[4]

Cytokinins: Delaying Senescence and Supporting Productivity

Cytokinins promote cell division, nutrient mobilization and delayed leaf senescence. They help maintain chlorophyll and photosynthetic activity, support shoot development and strengthen source–sink relationships. Under stress, maintaining functional leaves for longer can contribute to continued biomass production and crop productivity.[5]

Abscisic Acid: The Stress Management Hormone

Abscisic acid is a major regulator of drought and other environmental stress responses. Under water deficit, ABA accumulation promotes stomatal closure, thereby reducing transpiration and helping plants conserve water. It also regulates seed dormancy and contributes

to adaptation to drought, salinity and heat. Understanding ABA signaling is therefore important for developing climate-resilient crops.[6]

Ethylene: Regulator of Ripening and Senescence

Ethylene is a gaseous plant hormone involved in fruit ripening, flower senescence and stress responses. Because it can move readily through plant tissues, it can influence nearby cells. Ethylene-related technologies are used for more uniform fruit ripening and harvest management in crops including banana, mango and tomato, helping improve market quality.[7]

Emerging Plant Growth Regulators

Brassinosteroids

Brassinosteroids are steroidal hormones associated with growth, photosynthesis, nutrient uptake and stress tolerance. Their role in improving antioxidant defense and plant performance under drought, salinity and heat has received increasing attention.[8]

Jasmonates and Salicylic Acid

Jasmonates participate in plant defense against insects, pathogens and abiotic stresses, activating protective responses during adverse conditions. Salicylic acid also contributes to defense and stress adaptation and has been associated with improved photosynthesis, antioxidant activity and stress tolerance in several crops.[2]

Strigolactones

Strigolactones regulate shoot branching, root architecture and interactions with beneficial soil microorganisms. Their emerging importance in nutrient-use efficiency and stress resilience makes them promising components of future crop management.[2]

Role of PGRs in Crop Production

PGRs can influence several stages of crop production. They can promote uniform seed germination and establishment, stimulate root development, maintain chlorophyll and photosynthetic performance, regulate flowering and fruit set, and improve yield and produce quality through effects on source–sink relationships and nutrient partitioning.[5]

Plant Growth Regulators and Stress Management

Climate variability has increased the frequency and severity of drought, heat, salinity and flooding. PGRs can help crops adjust to these conditions by regulating water relations, antioxidant defense, photosynthesis and metabolism. ABA and salicylic acid are particularly relevant to drought responses, while brassinosteroids and cytokinins can support photosynthetic

machinery and membrane stability during heat stress. Several PGRs also enhance antioxidant activity and ion balance under salinity.[2,6,8]

Precision Agriculture and PGR Application

The benefits of PGRs depend strongly on applying the right product at the right concentration and developmental stage. Precision agriculture technologies such as drones, sensors and smart spraying systems offer opportunities to deliver PGRs more accurately according to crop requirements. Such approaches can reduce chemical wastage, improve application efficiency and support environmentally responsible crop management.

Challenges in PGR Use

PGRs are not universally beneficial at every concentration or growth stage. Incorrect concentration, unsuitable timing, crop-specific responses, environmental variability and regulatory restrictions can result in poor performance or undesirable effects. Therefore, PGRs should be selected and applied according to crop-specific recommendations and scientifically validated practices.

Future Prospects

Research is expanding towards novel signaling molecules, improved understanding of hormone pathways, gene editing, nano-formulations and precision delivery systems. These developments may allow more targeted manipulation of crop growth while reducing input losses. Combining PGR knowledge with precision agriculture could provide new approaches for improving productivity under changing climatic conditions.

Conclusion

Plant Growth Regulators are small molecules with substantial effects on crop growth, development and stress adaptation. Their judicious use can improve germination, rooting, flowering, fruiting, ripening, yield and quality while helping crops cope with environmental stress. As agriculture faces increasing resource and climate constraints, scientifically based PGR management, farmer awareness and improved delivery technologies will be important for realizing their potential in sustainable crop production.

References

1. Rademacher W. 2023. Plant growth regulators: Functions and applications in modern agriculture. Agronomy. 13(5): 1264.

2. Wani S.H., Kumar V., Khatoon S., Rather M.A. 2024. Emerging plant hormones and their role in climate-resilient agriculture. Front. Plant Sci. 15: 1412038.
3. Kumar P., Singh R., Sharma A., Verma S. 2023. Role of auxins in root development and crop productivity. J. Plant Growth Regul. 42(8): 4821–4838.
4. Singh D., Yadav R.K., Kumar A., Singh V. 2023. Gibberellins in crop production and yield enhancement. Physiol. Mol. Biol. Plants. 29(11): 2365–2380.
5. Hasanuzzaman M., Bhuyan M.H.M.B., Zulfiqar F., Raza A., Mohsin S.M., Mahmud J.A. et al. 2023. Plant responses and tolerance mechanisms against abiotic stress. Antioxidants. 12(4): 843.
6. Zhang H., Li X., Wang Y., Chen S. 2023. Abscisic acid signaling and stress adaptation in crop plants. Int. J. Mol. Sci. 24(17): 13218.
7. Iqbal N., Khan N.A., Ferrante A., Trivellini A., Francini A., Khan M.I.R. 2024. Ethylene signaling and crop productivity under changing environments. Front. Plant Sci. 15: 1387642.
8. Sharma A., Singh S., Kumar V., Prasad R. 2024. Brassinosteroids and stress tolerance in crop plants: Recent advances. Plants. 13(2): 317.

Volume: 06 Issue No: 09

FROM RESEARCH TO THE FIELD: THE ROLE OF TECHNOLOGY TRANSFER IN TRANSFORMING INDIAN AGRICULTURE

Article ID: AG-V06-I09-44

Bindhu. T. Yaladoodi* and Dr.Pradeep kumar. T. L

*PG scholar, Professor, Department of Agricultural Extension Education, KSNUAHS, Shivamogga, Karnataka, India-577412

*Corresponding Author: Bindhu T Yaladoodi

Abstract

Agricultural development depends not only on the generation of new technologies but also on their effective transfer and adoption by farmers. Technologies developed through agricultural research can improve productivity, profitability, resource-use efficiency and sustainability, but their benefits are realized only when they reach the farming community in a form that farmers can understand, test and apply. Technology transfer is therefore an important link between agricultural research and field-level practice. In India, institutions such as the Indian Council of Agricultural Research (ICAR), State Agricultural Universities, Krishi Vigyan Kendras (KVKs), Agricultural departments, Farmer organizations and Private agencies play important roles in disseminating improved agricultural technologies. The traditional technology-transfer approach has increasingly evolved into a more participatory and demand-driven agricultural innovation system involving farmers, researchers, extension personnel, markets and private organizations. Demonstrations, training programmes, field days, farmer-to-farmer extension, mobile-based advisories, social media and digital platforms have created new opportunities for faster dissemination. However, constraints such as inadequate extension personnel, lack of awareness, limited digital literacy, high cost of technologies, poor availability of inputs and location-specific problems can restrict adoption. Strengthening research–extension–farmer linkages and combining conventional and digital extension approaches can make technology transfer more effective, inclusive and farmer-oriented.

Keywords: Agricultural technology, technology transfer, agricultural extension, technology dissemination, KVKs, farmer adoption, digital extension, agricultural innovation.

Introduction

Agriculture is continuously changing with the development of improved crop varieties, farm machinery, precision farming technologies, climate-resilient practices, biological inputs, improved livestock technologies and digital agricultural services. However, developing a technology is only the first step. The real impact of agricultural research is achieved when the technology reaches farmers and is successfully used under actual farm conditions. Technology transfer in agriculture can be understood as the process through which knowledge, technologies, practices, products and innovations generated through research are communicated, demonstrated, adapted and ultimately applied by farmers**.** It serves as a bridge between the laboratory and the field.

The traditional agricultural extension system largely viewed technology transfer as a one-way process in which researchers generated technologies, extension personnel communicated them and farmers adopted them. However, agricultural development has become more complex, and this linear model is gradually giving way to a more interactive agricultural innovation system. FAO emphasizes that agricultural research and extension increasingly need to move beyond a purely technology-transfer approach towards systems that enable innovation and involve farmers and other stakeholders in the process.

In India, the Indian Council of Agricultural Research (ICAR), State Agricultural Universities, Krishi Vigyan Kendras, government departments, private organizations, NGOs, farmer organizations and other stakeholders contribute to agricultural technology dissemination. ICAR identifies frontline extension for technology application, adoption, knowledge management and capacity development as an important part of its mandate. Thus, effective technology transfer is not simply about **"giving technology to farmers"**. It is about ensuring that the technology is relevant to farmer's needs, understandable, affordable, locally adaptable and supported by appropriate inputs, skills and services.

What is Agricultural Technology Transfer?

Agricultural technology transfer refers to the process of moving useful agricultural knowledge, technologies, practices, products and innovations from research and development

institutions to farmers and other users, so that they can be understood, tested, adapted and applied in actual farming situations.

According to the **FAO**, technology transfer broadly involves processes through which **knowledge, goods and other resources are exchanged among different stakeholders, leading to the spread and application of technology**. FAO also recognizes *diffusion of research* and *innovation adoption* as closely related concepts. Technology may include both **material technologies** such as improved seed varieties, farm machinery, fertilizers, agrochemicals and improved breeds and **knowledge-based technologies**, such as improved crop management, integrated pest management, soil and water management and other farming practices.

Therefore, agricultural technology transfer is **not simply the distribution of a new technology**. It involves a series of activities such as **technology generation, testing, adaptation, demonstration, dissemination, farmer training, adoption and feedback**. FAO describes this process as a flow from science and technology generation through testing, adaptation, dissemination, diffusion and adoption.

Why is Technology Transfer Important?

Agricultural research produces a large number of technologies every year. However, the existence of a technology does not automatically lead to its adoption. For example, a research institution may develop a high-yielding variety, but farmers need to know: **What is the variety? Where is it suitable? How should it be cultivated? What inputs are required? What are its benefits? Where can quality seed be obtained?** Technology transfer connects these questions with practical solutions.

Agricultural technology transfer is important because the success of agricultural research depends not only on developing new technologies but also on ensuring that these technologies reach farmers and are effectively used in real farming situations. It acts as a bridge between **research institutions, extension agencies and farmers**, helping to convert scientific knowledge into practical solutions. Effective technology transfer enables farmers to gain knowledge and skills about improved crop varieties, farm machinery, pest and disease management, soil and water conservation, climate-resilient practices and other innovations. It can contribute to improved productivity, reduced production costs, better resource-use efficiency and increased farm income. Technology transfer also helps identify whether a technology is suitable for local soil, climate and socio-economic conditions through field demonstrations and on-farm testing. At

the same time, farmers can provide feedback about the difficulties they face, helping researchers and extension personnel modify technologies according to field realities. With the growing use of mobile phones, social media and digital advisory platforms, technology transfer can now reach farmers more quickly and across wider geographical areas. Thus, effective agricultural technology transfer is essential for transforming research findings into **practical, profitable and sustainable farming solutions**.

The Research–Extension–Farmer Linkage:

Effective technology transfer requires strong interaction among three major components: **Research, Extension and Farmers.** Researchers develop or improve technologies based on scientific knowledge. Extension personnel translate this scientific knowledge into practical recommendations and facilitate demonstrations, training and advisory services. Farmers then test and apply the technology under their own farming conditions. However, the process should not end with farmers. Farmers' experiences and feedback should return to researchers. Thus, the modern process can be represented as: **Research → Extension → Farmer → Feedback → Research**

FAO describes effective technology dissemination as requiring linkages among the research system, extension system and farmer/client system, with extension also communicating field-level problems and feedback back to research institutions. This feedback mechanism is particularly important because a technology that performs well under experimental conditions may require modification when introduced into different soils, climates, farming systems or socio-economic conditions.

Major Challenges in Technology Transfer

Agricultural technology transfer faces several challenges that can prevent useful technologies from reaching farmers and being adopted effectively. **High cost and limited availability of inputs** such as quality seed, machinery and other resources can discourage farmers from adopting new technologies. **Weak research–extension–farmer linkages** may also result in technologies that do not fully address farmer's local needs. **Limited extension personnel and inadequate training** can reduce the quality and reach of technical guidance. Differences in **soil, climate, farm size and socio-economic conditions** may affect the suitability of a technology in different areas. Farmers may also hesitate to adopt unfamiliar technologies because of **risk, uncertainty and resistance to changing traditional practices**. Therefore,

effective technology transfer requires strong institutional linkages, location-specific demonstrations, continuous farmer support and a participatory approach.

Digital Technology: A New Pathway for Technology Transfer

Digital technology has opened a new and faster pathway for transferring agricultural technologies from research institutions and extension agencies to farmers. Earlier, agricultural information mainly reached farmers through extension workers, demonstrations, training programmes, radio, television and printed materials. Today, mobile phones, smartphone applications, YouTube, WhatsApp, social media, web portals and digital advisory platforms allow farmers to access agricultural information almost instantly. These tools can help farmers receive timely information on improved cultivation practices, pest and disease management, weather, market prices, government schemes and other farm-related decisions. FAO notes that digital agricultural extension and advisory services have considerable potential to improve the accessibility, delivery and reach of information and services for smallholder farmers.

In India, ICAR has also promoted ICT-based extension through mobile applications, social media, YouTube and other digital platforms to improve the dissemination of agricultural technologies and reach farmers who may otherwise be difficult to contact through conventional extension methods. Recent developments such as **Kisan Sarathi 2.0** are further strengthening real-time interaction between farmers and agricultural experts through call centres, mobile applications and web-based systems. Similarly, the launch of **Bharat-Vistaar in February 2026** represents a move towards AI-enabled, multilingual and data-driven agricultural advisory services, providing information related to weather, markets and crop management through digital channels. However, digital technology cannot completely replace personal extension services. Limited internet connectivity, affordability of digital devices, digital literacy and unequal access among rural communities can restrict its benefits. FAO therefore emphasizes the need to address the digital divide and strengthen farmers' digital skills so that digital extension becomes more inclusive. Thus, digital technology should be viewed as a **complement to conventional extension**, combining the wide reach and speed of digital platforms with the trust, practical guidance and personal interaction provided by extension professionals.

Conclusion

Agricultural technology transfer is the bridge that connects scientific research with farmer’s fields. The success of agricultural research ultimately depends on how effectively useful

technologies are communicated, demonstrated, adapted and adopted by farming communities. India has a strong network of institutions such as ICAR, State Agricultural Universities, KVKs, agricultural departments and farmer organizations that contribute to this process.

However, the future of technology transfer should move beyond a simple **"researcher-to-farmer"** model. Farmers should be active participants in identifying problems, testing technologies, providing feedback and developing locally suitable solutions. Conventional approaches such as demonstrations, training and field visits should be strengthened through farmer-to-farmer extension, institutional partnerships and digital communication.

The goal should not be simply to **transfer more technologies**, but to **transfer the right technologies to the right farmers at the right time in the right form**. When technology transfer becomes participatory, demand-driven, inclusive and supported by continuous feedback, agricultural innovations can move beyond research laboratories and create meaningful improvements in farm productivity, profitability, resilience and sustainability.

References

Food and Agriculture Organization of the United Nations (FAO), (2026), *Agricultural innovation systems*. FAO, Research and Extension Systems.

Food and Agriculture Organization of the United Nations (FAO), (2026), *Extension and advisory services*. FAO, Research and Extension Systems.

Food and Agriculture Organization of the United Nations (FAO), (2023), *Guide on digital agricultural extension and advisory services*. FAO, Rome. ISBN 978-92-5-137561-7.

Indian Council of Agricultural Research (ICAR), (2026), *Krishi Vigyan Kendras (KVKs)*. ICAR, New Delhi.

Indian Council of Agricultural Research (ICAR), (2026), *Achievements of Agricultural Extension Division*. ICAR, New Delhi.

Sah, U., Singh, S. K., & Pal, J. K. (2021), Farmer-To-Farmer Extension (F2FE) approach for speedier dissemination of agricultural technologies: A review. *The Indian Journal of Agricultural Sciences*, *91*(10), 1419–1425. https://doi.org/10.56093/ijas.v91i10.117403

Gajbhiye, R., Nain, M. S., Singh, P., & Chahal, V. P. (2015), Developing linkages for agricultural technology transfer: A case study of research institution and voluntary organization partnership. *The Indian Journal of Agricultural Sciences*, *85*(6). https://doi.org/10.56093/ijas.v85i6.49257

Kumbhare, N. V., Dubey, A. V., Kishore, N., Singh, K., & Maurya, P. P. (2020), Strengthening the agricultural technology dissemination through institutional partnership-based extension model. *The Indian Journal of Agricultural Sciences, 90*(5). https://doi.org/10.56093/ijas.v90i5.104333

Chahal, V. P., et al. (2015). Assessing knowledge gaps of para extension workers for improving their capacity in dissemination of farm technology. *The Indian Journal of Agricultural Sciences, 85*(2), 229–223.

Volume: 06 Issue No: 09

USE OF TRIACONTANOL FOR HIGHER PRODUCTION IN ARID ZONE FRUIT PLANTS

Article ID: AG-V06-I09-45

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture, SKNAU,

Jobner -303329, Rajasthan, India

Introduction

Triacontanol (TRIA) is a naturally occurring, long-chain aliphatic fatty alcohol that functions as a plant growth-promoting substance. It is also known as 1-triacontanol, n-triacontanol or myricyl alcohol. Triacontanol is found naturally in the waxes of plants, particularly in alfalfa (*Medicago sativa*) leaves and beeswax. It has been investigated and used in agriculture as a growth regulator to improve plant growth, photosynthetic activity, nutrient utilization and crop productivity.

Basic characteristics:

Characteristic	Description
Chemical name	1-Triacontanol
Common name	Myricyl alcohol
Molecular formula	$C_{30}H_{62}O$
Molecular weight	Approximately 438.82 g/mol
Chemical class	Long-chain primary fatty alcohol
Carbon chain	30 carbon atoms
Nature	Naturally occurring plant growth-promoting compound
Solubility	Practically insoluble in water
Agricultural use	Plant growth regulator / biostimulant

Triacontanol is not a conventional mineral fertilizer. It is used in very small quantities to stimulate plant physiological processes and improve the efficiency with which plants utilize available water and nutrients.

Types of Triacontanol: Triacontanol is not conventionally divided into different plant-hormone classes. In agricultural practice, it is classified according to its chemical form, source and commercial formulation.

Classification

Chemical form	Natural triacontanol; synthetic triacontanol
Source	Plant-derived; beeswax-derived; commercially synthesized
Formulation	Emulsifiable concentrate (EC); soluble or dispersible formulations; nano-formulations
Application	Foliar spray; seed treatment; root-zone application

Important distinction: These are practical classifications, not separate hormone types. The active compound is the same 30-carbon fatty alcohol, although purity, formulation and delivery method can differ.

Importance of Triacontanol in Arid Zone Fruit Plants: Arid and semi-arid regions, including western Rajasthan, experience high temperature, low and erratic rainfall, soil salinity and limited irrigation water. Fruit crops such as ber, pomegranate, aonla, date palm, bael and karonda are important components of these production systems. Triacontanol may support fruit-tree performance by improving physiological efficiency, particularly when plants experience environmental stress. May support vegetative growth, leaf activity, flowering, fruit development and yield potential under arid conditions. Potentially improves photosynthetic activity, plant water relations, nutrient uptake and stress tolerance. A 2024 study specifically investigated triacontanol for alleviating salinity stress and improving fruit storability in pomegranate.

Aonla (Phyllanthus emblica): May help maintain metabolic activity and canopy growth, with possible benefits to fruit development when the treatment is suitable for the crop and growing conditions.

Date palm (*Phoenix dactylifera): Its potential value lies in supporting photosynthesis, nutrient utilization and physiological performance under heat and water stress.

Triacontanol may support growth and stress response, but crop-specific field validation is needed before recommending routine commercial use. The evidence for triacontanol's general plant-growth and stress-mitigation effects is substantial, but responses vary with species, concentration, formulation and environment. Benefits should not be assumed to be identical across arid fruit species.

Major areas of importance

- Enhances photosynthetic efficiency and chlorophyll-related activity.
- Supports vegetative growth and canopy development.
- May improve nutrient uptake and metabolic efficiency.
- Helps plants cope with certain abiotic stresses, including salinity and water deficit.
- May support flowering, fruit development, fruit quality and productivity.
- May contribute to more efficient use of limited agricultural inputs.

Mechanism of Action of Triacontanol in Arid-Zone Fruit Plants: Triacontanol acts through several interconnected physiological and biochemical processes. Its initial site of action is not completely understood, but research has identified signaling and metabolic responses associated with its application.

Detailed physiological mechanisms

1. Stimulation of photosynthesis: Triacontanol may increase chlorophyll content, photosynthetic enzyme activity and CO_2 assimilation. Greater photosynthetic activity can improve carbohydrate availability for fruit growth.

2. Activation of metabolic enzymes: Triacontanol has been associated with changes in enzyme activities involved in carbon and nitrogen metabolism, supporting plant growth and biomass production.

3. Improvement in nutrient uptake: It may influence the uptake and utilization of essential nutrients such as nitrogen, phosphorus and potassium, which are important for canopy development and fruit production.

4. Regulation of stress responses: Triacontanol can influence antioxidant defense, stress-associated gene expression and physiological processes that help plants cope with salinity and other environmental stresses.

5. Regulation of water relations: Research suggests that triacontanol may influence water-related processes, including aquaporin-associated responses, helping maintain plant water status

under some stress conditions.

6. Signal transduction: The proposed secondary messenger 9-β-L(+)-adenosine is associated with the rapid response to triacontanol. However, the complete signaling pathway and its specific role in different fruit trees remain incompletely established.

Practical Uses of Triacontanol in Arid-Zone Fruit Plants: Triacontanol can be considered as a supplementary plant growth regulator in fruit production, particularly when the objective is to improve physiological efficiency rather than directly supply nutrients.

Practical use	Potential benefit in fruit orchards
Vegetative growth	Supports shoot growth, leaf development and canopy establishment
Photosynthetic enhancement	Supports carbohydrate production and source activity
Flowering and fruit development	May improve reproductive growth and fruit development under suitable conditions
Fruit retention and yield	May contribute indirectly through improved plant physiological condition; fruit-retention effects require crop-specific verification
Heat and drought stress	May support stress-response mechanisms, but cannot replace irrigation
Salinity management	May improve physiological responses to salinity; pomegranate research has investigated this application
Fruit quality	May influence fruit quality attributes, depending on species, treatment and growing conditions
Nursery and young plants	Potential application for supporting growth, subject to appropriate dose validation

Triacontanol has been reviewed for its effects on fruit-crop growth, flowering, yield and quality. Nevertheless, not every listed application has been independently validated in each arid-zone fruit species.

Effective Concentration of Triacontanol in Arid-Zone Fruit Plants: Triacontanol is biologically active at very low concentrations. Its effectiveness depends on the crop species, formulation, plant age, application stage, environmental conditions and spray frequency.

Published studies across plant species report responses over a range of concentrations, including sub-ppm levels.

A. General concentration guide: The following is a **preliminary range for research and field-trial planning**, not a validated, crop-specific recommendation for all arid-zone fruit trees.

Triacontanol concentration	Potential application / interpretation
0.1 ppm	Low-dose treatment for preliminary screening
0.5 ppm	Low-concentration treatment for physiological response evaluation
1.0 ppm	Commonly investigated low-dose level in plant growth regulator research
1.5 ppm	Higher low-dose treatment for comparison in a concentration-response trial
2.0 ppm	Upper screening treatment in a preliminary trial; not a universal recommendation

Important: These are proposed screening concentrations, not proof that 1 ppm or any other concentration is optimal for ber, pomegranate, aonla, date palm or bael. A validated optimum for one species cannot automatically be transferred to another.

B. Suggested preliminary trial for arid fruit crops: For a research orchard, a small replicated trial may compare a water-treated control with 0.5, 1.0 and 1.5 ppm triacontanol, using a registered or otherwise legally appropriate formulation. The concentration range should be adjusted to the product label and prior crop-specific evidence.

C. Preparation of triacontanol spray solution: For dilute aqueous solutions, 1 ppm is approximately 1 mg of active ingredient per litre of final solution.

Target concentration	Active triacontanol required for 1 litre	Active triacontanol required for 100 litres
0.5 ppm	0.5 mg	50 mg
1.0 ppm	1 mg	100 mg
1.5 ppm	1.5 mg	150 mg
2.0 ppm	2 mg	200 mg

These values refer to **pure active ingredient**, not the total quantity of a commercial formulation. Commercial triacontanol products may contain different concentrations and require formulation-specific dilution calculations. Do not weigh or measure a commercial product as though it were pure triacontanol.

Precautions for orchard application:

- Follow the registered product label and crop-specific directions.
- Conduct a small-scale phytotoxicity trial before treating the entire orchard.
- Avoid spraying during extreme heat, strong winds or conditions that cause rapid droplet evaporation.
- Use clean water and ensure proper dispersion of the formulation.
- Do not assume that a higher concentration will produce a greater response.
- Avoid mixing with other plant growth regulators or pesticides unless compatibility has been established.
- Maintain appropriate irrigation, nutrition and soil management; triacontanol is not a substitute for these practices.

Role of Triacontanol in Arid-Zone Fruit Plants: Triacontanol may have an important supplementary role in sustainable fruit production in arid and semi-arid regions.

Role in horticultural productivity and the national economy

1. **Improved orchard productivity:** Potential enhancement of photosynthesis and plant growth may contribute to fruit yield when other growth-limiting factors are adequately managed.
2. **Climate-stress management:** Its potential to improve plant stress responses may be useful in regions facing high temperatures, irregular rainfall and saline irrigation water.
3. **Fruit quality and market value:** Physiological improvements may support fruit development and quality, although marketable gains must be verified in field trials.
4. **Resource-use efficiency:** Better nutrient utilization and physiological performance may complement efficient irrigation and fertilizer management.
5. **Farmer income and rural livelihoods:** Where treatment produces consistent economic benefits, it may contribute to orchard profitability, particularly in fruit-based farming systems.

6. **Research and technology development:** Crop-specific trials can help identify effective formulations, concentrations and application schedules for Rajasthan's arid fruit crops.

Conclusion

Triacontanol is a naturally occurring, 30-carbon fatty alcohol with plant growth-promoting activity. It has potential applications in arid-zone fruit crops such as ber, pomegranate, aonla, date palm and bael. Its reported physiological effects include enhancement of photosynthesis, nutrient uptake, enzyme activity, plant growth and stress-response mechanisms. In fruit production, triacontanol may support vegetative growth, flowering, fruit development, quality and productivity. Its potential role in salinity mitigation is particularly relevant to pomegranate cultivation, although responses depend on treatment conditions and the production environment. Triacontanol should be considered a supplementary biostimulant rather than a replacement for irrigation, fertilizers or sound orchard management. Since optimal concentrations and application schedules are not established universally for arid-zone fruit species, crop-specific research and adherence to registered product directions are essential for reliable and economical use.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article on Auxin.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

UTILIZATION OF GLYPHOSATE FOR BETTER PRODUCTION IN ARID ZONE FRUIT PLANTS

Article ID: AG-V06-I09-46

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture, SKNAU,

Jobner -303329, Rajasthan, India

Introduction

Glyphosate is a broad-spectrum, systemic, post-emergence herbicide widely used for the control of annual and perennial weeds in agricultural and non-agricultural areas. It belongs to the chemical group of phosphonoglycine herbicides.

- **Chemical name:** N-(phosphonomethyl)glycine
- **Molecular formula:** $C_3H_8NO_5P$
- **Mode of action:** Inhibition of the 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) enzyme.
- **Nature:** Non-selective, systemic herbicide.
- **Absorption:** Primarily through green leaves and other green plant tissues.
- **Translocation:** Moves through the phloem toward actively growing tissues, including roots, rhizomes and shoot meristems.

Glyphosate is particularly relevant to arid and semi-arid fruit production systems, such as those growing ber, aonla, pomegranate, date palm, bael and other drought-adapted fruit crops, because weed competition for limited soil moisture and nutrients can reduce crop growth and productivity.

Types or Classification of Glyphosate: Glyphosate can be classified according to its chemical nature, mode of action, application timing and commercial formulation.

Basis of classification	Type or category
Chemical group	Phosphonoglycine

Basis of classification	Type or category
Herbicide selectivity	Non-selective
Movement in plant	Systemic
Time of application	Post-emergence
Weed control action	Primarily foliar, with translocation to other tissues
HRAC/WSSA mode-of-action group	Group 9 (EPSPS inhibitor)
Formulation	Soluble concentrates, soluble salts and ready-to-use products

Common formulation types

- Glyphosate isopropylamine salt
- Glyphosate potassium salt
- Glyphosate ammonium salt
- Glyphosate dimethylamine salt

These formulations differ in their salt form, concentration, solubility and product characteristics. The active glyphosate molecule is responsible for the herbicidal action. Different formulations are not necessarily interchangeable on a volume-for-volume basis. Glyphosate is not a residual pre-emergence herbicide in the conventional sense. It primarily controls emerged, actively growing weeds and generally does not provide reliable season-long prevention of new weed emergence.

Mechanism of Action of Glyphosate in Arid Zone Fruit Plants: Glyphosate acts on weeds growing in and around fruit orchards. It does not selectively target weeds while sparing fruit trees; its safety in orchards depends primarily on preventing herbicide contact with the crop.

Relevance to arid fruit orchards: In arid regions, weeds compete with fruit trees for limited soil moisture and nutrients. When glyphosate successfully controls weeds, the reduction in competition may improve the availability of soil water and nutrients to the fruit trees. However, glyphosate itself does not stimulate root growth, photosynthesis or drought resistance in fruit plants.

Importance of Glyphosate in Arid Zone Fruit Plants: Glyphosate may have an important role in integrated weed management in arid and semi-arid fruit orchards.

Reduction of weed competition: Arid-zone fruit crops often grow under limited rainfall and irrigation. Weeds compete with fruit trees for available soil moisture, nutrients and space. Effective weed control can reduce this competition.

Improved water-use efficiency of orchards: By suppressing actively growing weeds, glyphosate can reduce the amount of water consumed by weeds, potentially leaving more soil moisture available to fruit trees.

Improved orchard management: Directed application in appropriate orchard inter-row or weed-strip areas may reduce the need for repeated manual or mechanical weeding, where the product is registered and its use is permitted.

Management of perennial weeds: Because glyphosate is systemic, it can move from treated foliage to underground growing tissues of susceptible perennial weeds. This makes it useful against certain established perennial weeds that are difficult to manage by superficial cutting alone.

Potential improvement in fruit productivity: Effective weed management can support fruit-tree growth, particularly during critical periods of water competition. However, increased yield or fruit quality is not guaranteed; results depend on weed species, orchard age, water availability, crop condition and overall management.

Practical Utility of Glyphosate in Arid Zone Fruit Plants

Ber (*Ziziphus mauritiana*) orchards: May be used for directed control of susceptible weeds in established ber orchards, subject to crop-specific registration and label directions. Weed suppression can help reduce competition for limited soil moisture.

Aonla (Phyllanthus emblica) orchard: Potential use in managing emerged weeds in orchard alleys or designated weed strips, where legally permitted. Avoid spray contact with green bark, suckers and foliage.

Pomegranate (*Punica granatum*) orchards: Directed weed control may help reduce weed competition in established orchards. Particular care is needed to prevent drift onto green shoots, leaves and exposed roots.

Date palm (Phoenix dactylifera) plantations: Potential utility for controlling susceptible weeds in inter-row areas and around established palms, only where the specific product use is permitted. Avoid contact with green palm tissues and off-target vegetation.

Bael (Aegle marmelos) and other arid fruit crops: May be considered for directed weed management in established orchards, depending on the product label, local registration and weed species.

Other practical applications

- Control of susceptible annual and perennial grasses and broad-leaved weeds.
- Weed suppression in orchard inter-row spaces and selected weed strips.
- Pre-planting weed control before establishing new fruit orchards, where permitted.
- Reduction of repeated manual weeding and associated labour requirements.
- Integration with mulching, cover cropping and mechanical weed management.

Effective Concentration of Glyphosate in Arid Zone Fruit Plants: The effective concentration of glyphosate depends on the weed species, growth stage, formulation, active ingredient concentration, spray volume and environmental conditions. There is no single universally effective or safe concentration for all arid-zone fruit crops.

General research and application reference

Application context	General reference
Susceptible annual weeds	Use only the product-label rate for the target weeds
Established perennial weeds	Some general orchard weed-management references report 1.0–1.5 kg active ingredient/ha as a directed application
Young fruit plantations	Requires particular caution; prevent all contact with green crop tissues
Established fruit orchards	Crop-specific registration and label directions must determine the permissible rate

The 1.0–1.5 kg a.i./ha figure is a general literature reference for certain perennial weeds, not a validated or blanket recommendation for ber, aonla, pomegranate, date palm or other arid fruit crops in India.

Important concentration and dose distinctions

- **Active ingredient (a.i.):** The actual quantity of glyphosate in a product.
- **Formulation concentration:** The amount of glyphosate or glyphosate salt in the commercial product, often expressed as g/L or g/kg.

- **Field application rate:** The amount of product or active ingredient applied per unit area, such as L/ha or kg a.i./ha.
- **Spray concentration:** The amount of formulated product mixed into a given volume of water.

These are not interchangeable measurements. For example, a dose expressed in kg a.i./ha cannot be converted directly into mL of commercial product per litre without knowing the exact formulation concentration, product label and intended spray volume.

Factors affecting effectiveness

1. Actively growing weeds generally respond better than drought-stressed weeds.
2. Weed species and growth stage influence susceptibility.
3. Rain shortly after application may reduce herbicide absorption.
4. Dust-covered foliage and poor spray coverage can reduce effectiveness.
5. Hard water and formulation characteristics may affect herbicide performance.

In arid regions, avoid assuming that higher concentrations will give better weed control. Excessive or off-label application can increase crop injury and environmental risks.

Precautions for use in fruit orchards

- Use only where the current product label and Indian registration permit the intended use.
- Use directed or shielded spraying equipment to minimize drift.
- Avoid contact with green bark, leaves, suckers, fruit and exposed roots.
- Do not spray during strong winds or under conditions that promote drift.
- Follow the label's rain-free period, personal protective equipment requirements, re-entry interval and other precautions.
- Do not assume that mature brown bark makes every fruit tree safe from glyphosate exposure.
- Integrate herbicide use with mulching, mowing and other appropriate weed-management methods.

Role of Glyphosate in the National Economy

Glyphosate may contribute indirectly to agricultural productivity and the rural economy through weed management.

Economic contribution	Potential benefit
Reduction in labour requirements	May lower expenditure on repeated manual weeding
Improved resource management	Reduces weed competition for scarce water and nutrients
Orchard productivity	May support productive growth when weeds are a significant limiting factor
Farm profitability	Potential reduction in weed-management costs
Agricultural operations	Can improve the timeliness and flexibility of orchard weed management
Reduced mechanical disturbance	May reduce the need for repeated soil cultivation in selected systems

Economic importance in arid and semi-arid regions

- In Rajasthan and other dryland regions, water scarcity and the cost of orchard maintenance are important production constraints. Effective weed management can help farmers use available resources more efficiently.
- However, glyphosate does not automatically increase farm income. The economic outcome depends on the cost of the herbicide, labour savings, weed-control efficacy, crop safety, fruit yield and market price. Incorrect use can cause crop losses and offset any potential savings.
- Its contribution to the national economy should therefore be evaluated as part of integrated weed management rather than as an independent yield-enhancing input.

Conclusion

Glyphosate is a systemic, non-selective, post-emergence herbicide that controls a wide range of susceptible annual and perennial weeds. It inhibits the EPSPS enzyme in the shikimate pathway, disrupting the synthesis of essential aromatic amino acids and eventually causing weed death. In arid-zone fruit orchards, glyphosate may be useful for managing weeds that compete with fruit trees for limited soil moisture, nutrients and other resources. Its potential applications include weed management in established ber, aonla, pomegranate, date palm and other fruit

orchards, provided the intended use is legally registered and consistent with the product label. Glyphosate is not a growth promoter, fertilizer or drought-tolerance chemical. Its benefits to fruit production are indirect and depend on successful weed management. The effective rate varies with the formulation, weed species and application conditions. Crop injury is possible if spray contacts green tissues. In conclusion, glyphosate can be a component of integrated weed management in arid-zone fruit production, but its use must be crop-specific, label-compliant and carefully directed to weeds. Combining appropriate herbicide use with mulching, mechanical weed control and sound orchard management can support sustainable fruit production

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article on Auxin.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

PREDISPOSING FACTORS AND DIAGNOSTIC APPROACHES FOR FETOMATERNAL DISPROPORTION IN LARGE ANIMAL OBSTETRICS

Article ID: AG-VO6-I09-47

A. Thangamani[1], B. Vigneshwaran[1], A. Sabarinathan[2], V. Prabaharan[3] and A. Elango[4]

[1]Assistant Professor, [3]Professor and Head, Dept. of Veterinary Gynaecology and Obstetrics

[2]Assistnat Professor, Veterinary Clinical Complex

[4]Dean, Veterinary College and Research institute, Salem-636 112

Tamil Nadu Veterinary and Animal Sciences University, Tamil Nadu, India

*Corresponding Author: A. Thangamani

Abstract

This paper discusses the predisposing factors and diagnosis of fetomaternal pelvic disproportion (FMD) in cattle, a leading cause of dystocia. The incidence of FMD varies by breed and is notably higher in dams carrying large or male fetuses. Heifers are particularly susceptible due to the anatomical mismatch between their underdeveloped pelvic cavities and fetal size. Fetal factors and maternal factors influence the fetomaternal pelvic disproportion.

Keywords: Fetomaternal pelvic disproportion, Cattle, Predisposing factors, Maternal factor, Fetal factors

Introduction

Dystocia, or difficult calving requiring assistance, is a major reproductive and economic problem in cattle due to high perinatal calf mortality (Youngquist & Threlfall, 2007). It is broadly classified into maternal and fetal causes (Jackson, 2004), with fetomaternal disproportion (FMD) being the leading cause in heifers (Colburn et al., 1997). FMD occurs when fetal size, especially birth weight, exceeds maternal pelvic capacity, obstructing normal parturition (Mee, 2008), and birth weight is considered the most critical determinant of calving ease (Zaborski et al., 2009). Price and Wiltbank (1978) demonstrated that 68.7% of primiparous Hereford heifers with pelvic area <200 cm² experienced dystocia compared to only 28% with larger pelvic area.

Fetomaternal Pelvic Disproportion (FMD):

Noakes et al. (2001) reported that 46% of dystocia cases in cattle are due to fetomaternal pelvic disproportion. Double-muscled European breeds are more predisposed, as deletion of an 11-nucleotide segment in the myostatin gene leads to muscular hypertrophy and increased dystocia risk (Kolkman et al., 2007). While mild cases are often managed by stockpersons, FMD is more common in heifers, though many hospital referrals involve mature cows with delayed intervention leading to fetal emphysema and enlargement. Such cases are frequently encountered under field conditions, where prolonged second-stage labor of 2-3 hours often results in secondary uterine inertia and hypoglycemia due to continuous straining. The multifactorial etiology of FMD is discussed in this paper.

Predisposing factors for FMD:

Foetal factors and maternal factors influence the fetomaternal disproportion.

1.Foetal factors:

1.1. Gestation length: Birth weight increases with gestation length (Mee, 2008). Average bovine gestation is ~283 days, with breed variations - 279 days in Holstein-Friesian and 287 days in Charolais (Zaborski et al., 2009). Late gestation fetal growth is ~0.5 kg/day in dairy (Jackson, 2004) and 0.1-0.25 kg/day in beef. Prolonged gestation is common with male fetuses and winter calvings (Noakes et al., 2001).

1.2 Parity of the dam: First parity calves have lower birth weight than second parity (Colburn et al., 1997), and larger dams produce larger calves (Noakes et al., 2001). Parity also influences gestation length (Mee, 2008). Calf weight and pelvic area contribute 33% and 12% to dystocia, respectively (Wolverton et al., 1991).

1.3. Sire: Paternal genetics affect dystocia via gestation length and fetal size (Holland & Odde, 1992), with greater effect in male calves (Laster et al., 1973).

1.4. Breed: Breed affects fetal growth and pelvic conformation. Dystocia rates are 6% in Holstein-Friesian, 9% in Charolais and up to 80% in Belgian Blue heifers (Holland & Odde, 1992). Crossbreeding reduces risk through heterosis.

1.5. Nutrition: Overfeeding in late gestation increases fetal weight and dystocia risk (Noakes et al., 2001), while undernutrition causes weak uterine contractions (Jackson, 2004). Excess feeding causes fat deposition in the birth canal, narrowing the pelvis without increasing calf size (Meijering, 1984; Bellows & Short, 1978).

1.6. Sex of calf: Male calves have longer gestation and higher birth weight, leading to more dystocia (Holland & Odde, 1992; Noakes et al., 2001).

1.7. Climatic factors: Season, temperature and humidity affect birth weight (Colburn et al., 1997). Winter-born calves are heavier due to increased uteroplacental blood flow (Holland & Odde, 1992) and hormonal changes that prolong gestation (Mee, 2008).

2. MATERNAL FACTORS:

2.1. Weight at service: Optimal breeding weight ensures adequate pelvic development and reduces FMD (Mee, 2008; Jackson, 2004; Andersen et al., 1993; King et al., 1993).

2.2. Parity: Dystocia is inversely related to parity. Mee et al. (2009) reported 93% dystocia in heifers vs 58% in multiparous cows, and Holstein heifers are 4.7 times more prone than cows (Johanson and Berger, 2003).

2.3. Age at calving: Younger heifers require more assistance (Meijering, 1984). Dystocia declines from 12% at 2 years to 2% at 3 years, 0.3% at 4 years and 0.5% at 5 years (Newman et al., 1993).

2.4. Condition at calving: Over conditioned dams accumulate pelvic fat, narrowing the birth canal (Noakes et al., 2001). Target BCS of 2.75-3.0 (5-point scale) or 540-570 kg mature weight is recommended (Mee, 2008).

2.5. Genetic makeup: Beef breeds have higher dystocia than dairy due to conformation differences (Zaborski et al., 2009). Breeds like Hereford, Angus, Limousin and Pinzgauer with smaller pelvic capacity are more predisposed.

DIAGNOSIS:

An accurate diagnosis begins with a thorough clinical history and physical examination. The history should document gestation length, breeding method (natural service or artificial insemination), parity, duration and progress of labor, and whether any prior interventions were attempted (including the timeframe and specific measures taken). Before examination, the perineal area must be meticulously cleaned with tap water or a potassium permanganate solution. Using a lubricated, gloved left hand, the clinician performs a careful per vaginum obstetrical examination to evaluate fetal presentation, position and posture, while assessing fetal size relative to the maternal pelvic inlet and birth canal. Although radiography can help identify pelvic fractures or callus formation that may obstruct fetal expulsion, its practical application is often limited in large animals. As noted by Youngquist and Threlfall (2007), if stenosis of the

cranial or posterior vagina is detected, a per rectal examination should also be performed to rule out uterine torsion. Palpation of the fetal head and limbs provides a preliminary estimate of fetal dimensions. In cases with normal fetal alignment, gentle traction may be attempted to facilitate delivery. However, if a clear mismatch between fetal size and maternal pelvic capacity is confirmed, the condition is diagnosed as fetomaternal disproportion (Drost, 2005).

Conclusion

Fetomaternal disproportion is a leading cause of dystocia in cattle. Management should consider the physiological status of dam and fetus. Heifers with low body weight are more susceptible, hence selection of replacement heifers with adequate mature weight and optimal BCS is essential. Pelvimetry is a useful screening tool; pelvic inlet area <200 cm^2 strongly predisposes to dystocia. Animals with pelvic fractures or congenitally small pelvis should not be used for breeding and should be culled to prevent maternal mortality. Case-specific intervention protocols improve delivery outcomes. Further studies are needed to assess whether accelerated fetal weight gain in third trimester is a key predisposing factor for FMD.

References

1. Andersen, K. J., Brinks, J. S., LeFever, D. G., and Odde, K. G. (1993). The factors associated with dystocia in cattle. Vet. Med. 88:764–776.

2. Bellows, R. A., Short, R. E., Anderson, D. C., Knapp, B. W., et al. (1971). Cause and effect relationships associated with calving difficulty and calf birth weight. J Anim Sci. 33(2):407-15.

3. Colburn, D. J., Deutscher, G. H., Nielsen, M. K., and Adams, D. C. (1997). Effects of sire, dam traits, calf traits, and environment on dystocia and subsequent reproduction of two-year-old heifers. J Anim Sci. 75(6):1452-60.

4. Drost, M. (2005). Management of Calving on Large Farms. 2nd Florida Dairy Road Show, pp: 42-52.

5. Holland, M. D., and Odde, K. G. (1992). Factors affecting calf birth weight: a review. Theriogenology. 38(5):769-98.

6. Jackson, P. G. G. (2004). Handbook of Veterinary Obstetrics. W B Saunders, pp: 261.

7. Johanson, J. M., and Berger, P. J. (2003). Birth weight as a predictor of calving ease and perinatal mortality in Holstein cattle. J Dairy Sci. 86(11):3745-55.

8. King, B. D., Cohen, R. D. H., McCormac, S., and Guenther, C. L. (1993). Maternal factors and the prediction of dystocia in beef heifers. Can. J. Anim. Sci. 73:431–435.

9. Kolkman, I., De Vliegher, S., Hoflack, G., Van Aert, M., et al. (2007). Protocol of the Caesarean section as performed in daily bovine practice in Belgium. Reprod Domest Anim. 42(6):583-9.

10. Laster, D. B., Glimp, H. A., Cundiff, L. V., and Gregory, K. E. (1973). Factors affecting dystocia and the effects of dystocia on subsequent reproduction in beef cattle. J Anim Sci. 36(4):695-705.

11. Mee, J. F. (2008). Prevalence and risk factors for dystocia in dairy cattle: a review. Vet J. 176(1):93-101.

12. Mee, J. F., Berry, D. P., and Cromie, A. R. (2009). Risk factors for calving assistance and dystocia in pasture-based Holstein-Friesian heifers and cows in Ireland. Vet J.

13. Meijering, A. (1984). Dystocia and Stillbirth in Cattle - A review of causes, relations and implications. Livest. Prod. Sci. 11:143-177.

14. Newman, S., et al. (1993). [PLEASE REPLACE WITH FULL DETAILS]

15. Noakes, D., Parkinson, T. J., and England, G. C. (2001). Arthur's Veterinary Reproduction and Obstetrics. Saunders, pp: 864.

16. Price, T. D., and Wiltbank, J. N. (1978). Dystocia in cattle. A review and implications. Theriogenology 9(3):195–219.

17. Wolverton, D. J., Perkins, N. R., and Hoffsis, G. F. (1991). Veterinary application of pelvimetry in beef cattle. Compend. Contin. Educ. Pract. Vet. 13:1315–1320.

18. Youngquist, R. S., and Threlfall, W. R. (2007). Current therapy in large animal theriogenology. Saunders Elsevier. St. Louis, Mo., pp: 1061.

19. Zaborski, D., Grzesiak, W., Szatkowska, I., Dybus, A., et al. (2009). Factors affecting dystocia in cattle. Reprod Domest Anim. 44(3):540-51.

Volume: 06 Issue No: 09

MINERAL NUTRITION AND ITS UPTAKE IN PLANTS

Article ID: AG-V06-I09-48

[1*]Afrin Frank B S, [1]Durga Prasad T S, [1]Gayathri K B, [1]Akshay K,

[1]Deiva Prakash V and [2]Sivaji M

[1]UG Student, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu -606 753, India

[2]Teaching Assistant Agricultural Biotechnology, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu- 606 753, India

Corresponding Author: Afrin Frank B S

Introduction

Plant mineral nutrition sits at the core of modern plant physiology, biochemistry, and agricultural biotechnology. Higher plants rely on at least 14 essential mineral nutrients absorbed directly from the soil solution to complete their vegetative and reproductive life cycles. These nutrients fall into two main categories based on whether their requirement equals or exceeds 0.1% of dry biomass:

- **Macronutrients:** Nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur.
- **Micronutrients:** Iron, manganese, copper, zinc, molybdenum, boron, chlorine, and nickel.

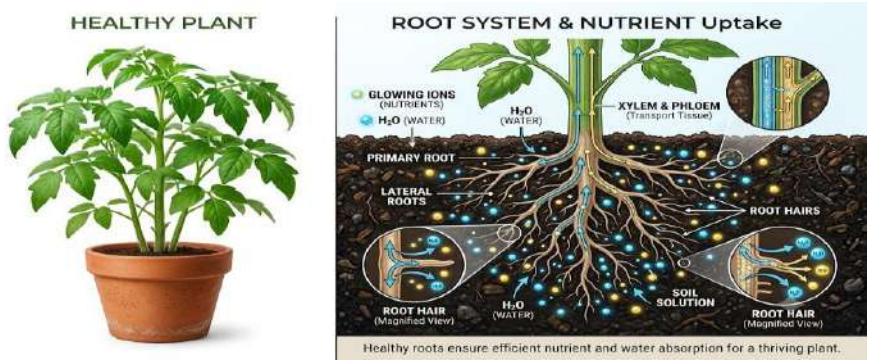


Figure 1. Picture depicting healthy plant's root system and its nutrient uptake

Beyond these core 14, beneficial elements like sodium (Na^+), silicon (Si), cobalt (Co), and selenium (Se) promote growth or stress resilience in specific taxa.

In field soils, mineral availability is constantly shifting due to physicochemical factors like soil pH, redox potential, cation exchange capacity, microbial immobilization, and water deficit. Abiotic stresses—such as drought, salinity, flooding, and heavy metal toxicity—severely disrupt the homeostatic networks that govern mineral acquisition. Modern biotechnology tackles these limits by combining molecular transporters, signal transduction cascades, genome editing (CRISPR-Cas9), and agricultural nanotechnology to optimize nutrient-use efficiency (NUE) and engineer stress-resilient crop varieties.

Essential Mineral Nutrients and Their Physiological Roles

Essential mineral elements act as indispensable structural constituents, osmotic regulators, and enzymatic cofactors across plant metabolic pathways.

TABLE 1: CLASSIFICATION, BIOCHEMICAL ROLES, KEY TRANSPORTERS, AND DEFICIENCY IMPACTS

Nutrient & Classification	Physiological & Biochemical Roles	Key Transporters & Sensors	Deficiency & Stress Impact
Nitrogen (N) (Macronutrient)	Core constituent of amino acids, proteins, nucleic acids, chlorophyll, and ATP; central driver of vegetative growth and yield.	NRT1 family (NRT1.1/CHL1 transceptor), NRT2 family (NRT2.1, NRT2.4), AMT1/2 family.	Stunted growth, leaf chlorosis starting in older leaves, reduced photosynthetic capacity and yield.
Phosphorus (P) (Macronutrient)	Component of ATP, nucleic acids, phospholipids, and sugar phosphates; central to energy transfer and signaling.	PHT1 family (PHT1;1–PHT1;9), PHO1 xylem loader, PHR1-SPX regulatory module.	Anthocyanin accumulation (purple/dark green foliage), restricted lateral root growth, severe yield loss.
Potassium (K) (Macronutrient)	Primary osmoticum; regulates guard cell turgor, stomatal movement, enzyme	AKT1, HAK5/KUP/KT family, TPK channels (tonoplast), SOS1 Na+/H+ interaction.	Marginal leaf chlorosis and necrosis, loss of turgor, extreme susceptibility to drought

	activation, and phloem loading.		and cold stress.
Calcium (Ca) (Macronutrient)	Structural component of cell walls (calcium pectate) and plasma membrane; primary second messenger in signaling.	CNGCs, GLRs, OSCA channels; ECA/ACA Ca2+-ATPases, CAX H+/ Ca2+ antiporters.	Necrosis of meristematic tissues, blossom end rot, bitter pit in fruit, disrupted intracellular signaling.
Magnesium (Mg) (Macronutrient)	Central atom of chlorophyll ring; cofactor for ATPases, Rubisco, and nucleic acid synthesis enzymes.	MGT/MRS2 family (AtMGT1, OsMGT3), tonoplast CBL2/3-CIPK complex regulatory targets.	Interveinal chlorosis on older leaves, reduced carbohydrate allocation to roots, photo-oxidative damage.
Iron (Fe) (Micronutrient)	Redox cofactor in cytochromes, ferredoxin, catalase, and peroxidase; essential for electron transport and chlorophyll synthesis.	IRT1 (Strategy I reduction), YSL family (Strategy II chelation), FRO2 reductase, FIT bHLH TF.	Interveinal chlorosis on young leaves, impaired photosynthetic electron transport, severe yield reduction.
Manganese (Mn) (Micronutrient)	Cofactor for PSII oxygen-evolving complex (Mn 4CaO5 cluster), superoxide dismutase (Mn-SOD), and lignin synthesis.	NRAMP1, MTP8 (CDF family vacuolar transporter), CPK21/23 and CBL1/9-CIPK23 regulation.	Interveinal chlorosis with necrotic spots, disintegrating thylakoid membranes, reduced photosynthetic efficiency.

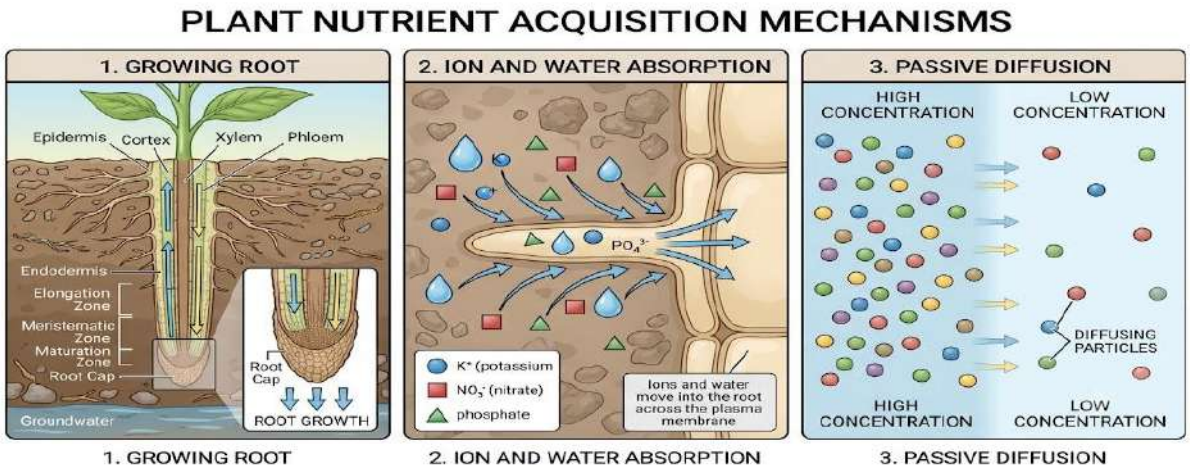


Figure 2. Plant nutrition acquisition mechanisms.

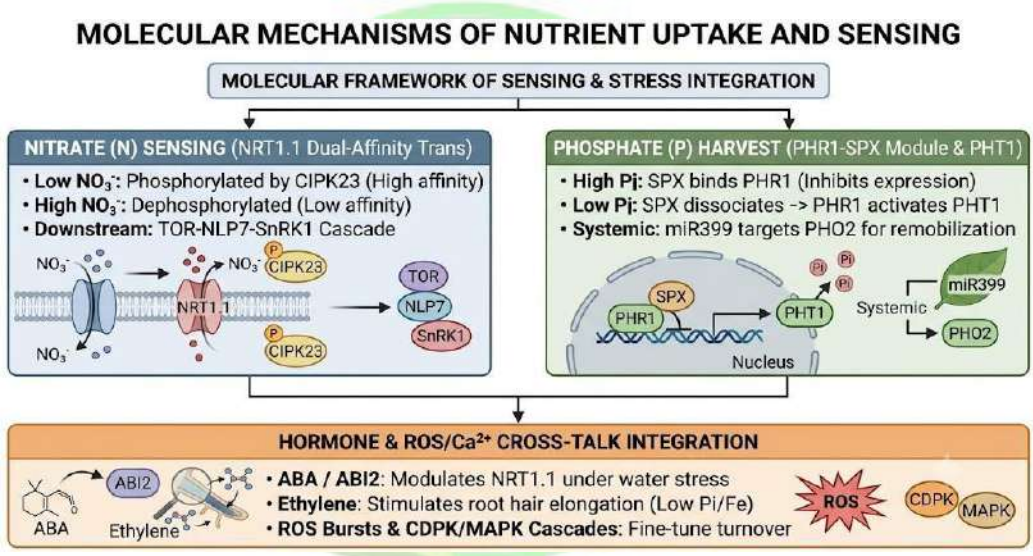


Figure 3. Molecular mechanisms of nutrient uptake and sensing.

Dual-Affinity Nitrate Sensing and Assimilation (NRT1.1 & NLP7)

Nitrate (NO^-) functions simultaneously as an essential nitrogen source and a signaling molecule regulating root system architecture, seed germination, and flowering. The plasma membrane-localized transceptor NRT1.1 (CHL1) couples nitrate sensing directly to uptake across wide concentration gradients.

- **Low Nitrate Availability (**< 1 mM**):** The protein CIPK23 (activated by calcineurin B-like proteins CBL1/9) phosphorylates NRT1.1 at Thr101, switching it into a high-affinity transporter.
- **Abundant Nitrate (**> 1 mM**):** Thr101 remains dephosphorylated, allowing NRT1.1 to operate as a low-affinity uptake system.

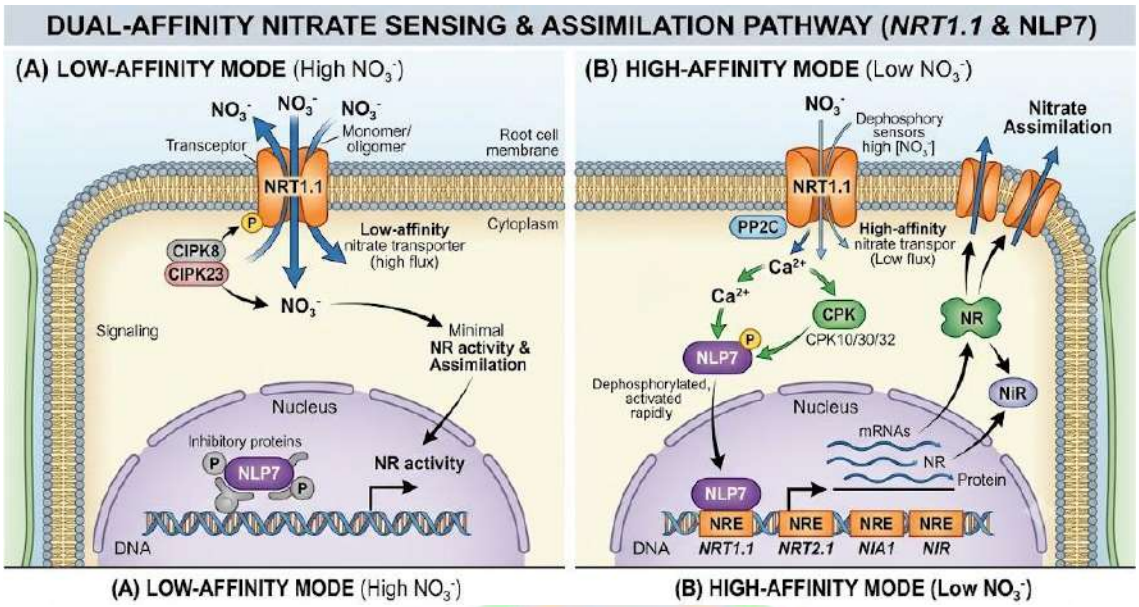


Figure 4. Dual-Affinity Nitrate Sensing and Assimilation (NRT1.1 & NLP7)

Intracellularly, nitrate signaling triggers rapid cytosolic calcium spikes that activate subgroup III Calcium-Dependent Protein Kinases (CPK10, CPK30, CPK32). These CPKs phosphorylate the master transcription factor NIN-LIKE PROTEIN 7 (NLP7) at Ser205, driving its movement into the nucleus. Active NLP7 then coordinates the rapid expression of primary nitrate response genes, including nitrate reductases (*NIA1*, *NIA2*) and high-affinity transporters (*NRT2.1*, *NRT2.2*). Conversely, under excessive ammonium (NH^+) levels, the CBL1/9-CIPK23 complex phosphorylates AMT1 family transporters (AMT1;1, AMT1;2) at their C-termini to inhibit ammonium influx and prevent ammonium toxicity.

Phosphate Starvation Responses (PHR1-SPX Module & PHT1 Family)

Inorganic phosphate (P_i) acquisition from soil is naturally constrained because it readily precipitates with aluminium/iron oxides in acidic soils or calcium in alkaline soils. Plants monitor internal P_i status via the PHR1-SPX regulatory module:

1. P_i-**Sufficient Conditions:** High intracellular inositol pyrophosphates (InsPPs) enable SPX domain-containing proteins to bind the master MYB transcription factor PHOSPHATE STARVATION RESPONSE 1 (PHR1), sequestering it and blocking its transcriptional activity.
2. P_i-**Deficient Conditions:** InsPP levels drop, causing SPX to disconnect from PHR1. Free PHR1 binds to P1BS cis-elements (GNATATNC) in the promoter regions of phosphate starvation-induced (PSI) genes. This activates high-affinity PHT1 family transporters

(PHT1;1, PHT1;4), purple acid phosphatases (PAPs), and microRNA miR399.

3. **Long-Distance Signaling:** Systemic miR399 moves through the phloem from shoots to roots to downregulate PHO2 (an E2 ubiquitin conjugase). This stabilizes PHO1 and PHT1 transporters to promote long-distance transport and internal remobilization.

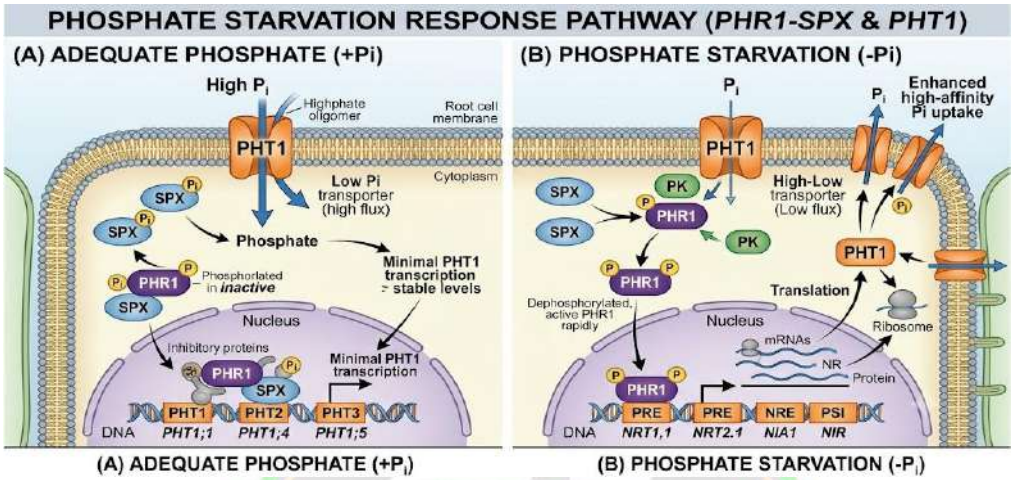


Figure 5. Phosphate starvation response pathway.

Potassium Dynamics and Osmotic Balance (AKT1, HAK5, TPKs)

Potassium (K^+) uptake across root epidermal cells during low-K^+ stress relies on the shaker-type channel AKT1 and the high-affinity K^+/H^+ symporter HAK5. When plants experience K^+ deprivation, plasma membrane hyperpolarization and reactive oxygen species (ROS) bursts trigger distinct cytosolic Ca^{2+} signatures. Membrane-bound CBL1/9-CIPK23 complexes then phosphorylate and activate both AKT1 and HAK5 to boost root K^+ uptake. At the same time, vacuolar reserves are mobilized via tonoplast CBL2/3-CIPK3/9/23/26 signaling modules that turn on tandem-pore potassium channels (TPK1, TPK3, TPK5), releasing stored K^+ into the cytosol to maintain cell turgor and metabolic balance.

Micronutrient Acquisition: Iron (Strategy I & II) and Manganese

Strategy I (Reduction Strategy — Non-Graminaceous Species): Plasma membrane H^+-ATPases (AHA2) pump protons outward to acidify the rhizosphere and solubilize Fe^{3+}. Ferric chelate reductase FRO2 reduces Fe^{3+} to Fe^{2+}, which is then imported across the plasma membrane by IRON-REGULATED TRANSPORTER 1 (IRT1). The transcription factor FIT pairs with bHLH TFs (bHLH38/39) once phosphorylated by CIPK11 to drive the expression of both *FRO2* and *IRT1*.

- **Strategy II (Chelation Strategy — Graminaceous Grasses):** Grasses synthesize phytosiderophores—such as deoxymugineic acid (DMA)—via nicotianamine synthase (NAS) and nicotianamine aminotransferase (NAAT). These phytosiderophores are released into the rhizosphere through TOM1 transporters to bind insoluble Fe^{3+}. The intact Fe^{3+}-DMA complexes are then absorbed into root cells by YELLOW STRIPE 1 / YS1-LIKE (YS1/YSL) transporters.

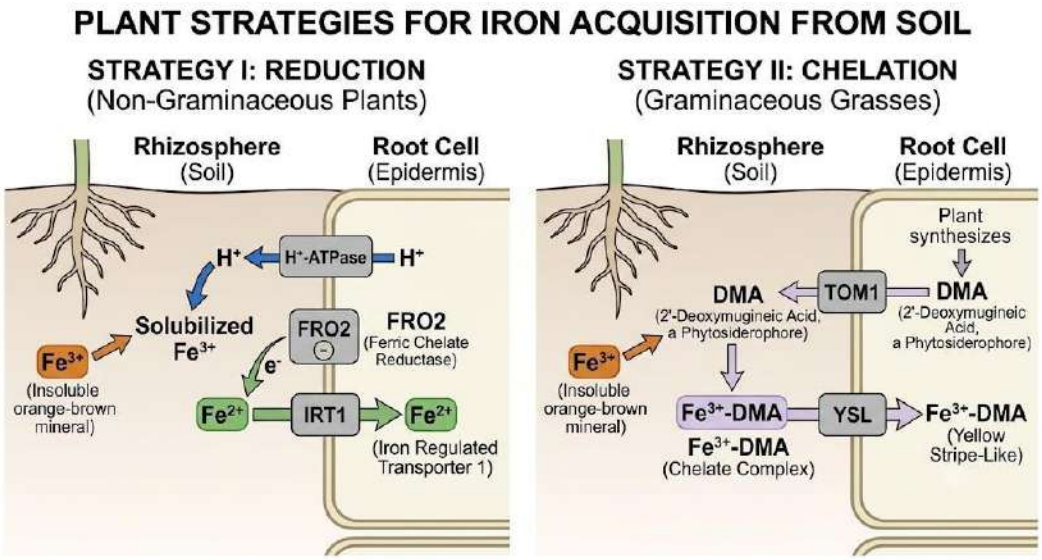


Figure 6. Plant strategies for iron acquisition from soil.

For manganese (Mn) homeostasis, the high-affinity transporter NRAMP1 is activated under Mn deficiency through CPK21/CPK23-mediated phosphorylation at Thr498. Under toxic high-Mn conditions, CBL1/9-CIPK23 complexes phosphorylate NRAMP1 at Ser20/22 to trigger clathrin-mediated endocytosis and degradation. Excess intracellular Mn^{2+} is sequestered into vacuoles by Metal Tolerance Protein 8 (MTP8), which is activated by CPK4/5/6/11 phosphorylation at Ser31/32.

Calcium Signaling in Plant Mineral Homeostasis

Calcium (Ca^{2+}) serves a structural role by maintaining cell wall rigidity (as calcium pectate) and membrane stability, while functioning as the primary secondary messenger decoding environmental and nutritional stimuli.

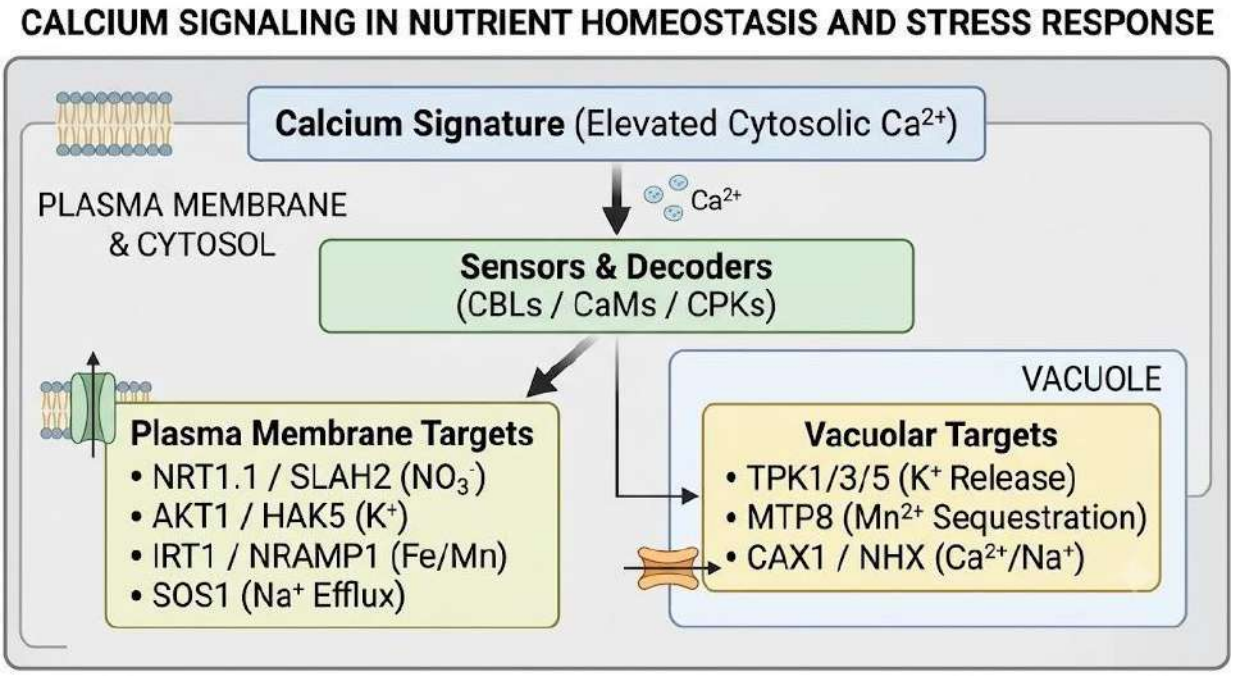


Figure 7: Calcium signalling in nutrient homeostasis and stress response

Stimulus-specific spatial and temporal fluctuations in cytosolic free Ca^{2+}—known as Ca^{2+} signatures—are created by coordinated Ca^{2+} influx through channel families (CNGCs, GLRs, OSCA, MscS-like) and efflux through P2A/P2B-type Ca^{2+}-ATPases (ECAs/ACAs) and CAX H^+/Ca^{2+} antiporters.

These signatures are decoded by primary Ca^{2+} sensor proteins, including:

- Calcineurin B-Like proteins (CBLs)
- Calmodulins (CaMs)
- CaM-Like proteins (CMLs)
- Calcium-Dependent Protein Kinases (CPKs)

Upon binding Ca^{2+}, these sensors undergo structural changes that regulate downstream target transporters, ion channels, and transcription factors across both the plasma membrane and tonoplast.

Heavy Metal Detoxification and Beneficial Element Dynamics

When plants encounter non-essential heavy metals (cadmium, lead, arsenic, chromium) or high sodium (salinity) in soil solutions, they activate calcium-dependent detoxification pathways:

Sodium Homeostasis & The Salt Overly Sensitive (SOS) Pathway

High salinity triggers a rapid cytosolic Ca^{2+} spike that is detected by CBL4 (SOS3) or CBL8. The resulting Ca^{2+}-CBL complex recruits and activates CIPK24 (SOS2), which phosphorylates the plasma membrane Na^+/H^+ antiporter SOS1 to accelerate Na^+ efflux. At the same time, tonoplast-bound CBL10-CIPK24 complexes turn on NHX antiporters to lock cytosolic Na^+ safely inside vacuoles.

Cadmium (Cd) & Arsenic (As) Detoxification

Cadmium enters root cells through permeable Ca^{2+} and Fe^{2+} channels. In response, CPK21 and CPK23 phosphorylate the cadmium transporter NRAMP6 at Ser489 and Thr505, blocking its Cd transport activity. Under arsenate [As(V)] stress, CPK23 phosphorylates the phosphate transporter PHT1;1 at Ser514 to trigger its endocytosis, stopping As(V) from entering. Arsenite [As(III)] transport via NIP1;1 is similarly regulated by direct CPK31 interactions.

Beneficial Elements

- **Silicon (**Si**):** Boosts structural rigidity, lowers transpiration, and stimulates antioxidant enzymes (AsA-GSH cycle) to mitigate drought, salinity, and heavy metal toxicity.
- **Selenium (**Se**):** At low concentrations, enhances redox balance by activating glutathione peroxidase.
- **Cobalt (**Co**):** Supports biological nitrogen fixation in leguminous symbioses.

In Vitro Mineral Nutrition & Chemical Speciation

Standard basal media such as Murashige and Skoog (MS) are widely used in plant tissue culture. Comparative studies highlight species-specific variations in net mineral utilization efficiency (the percentage of supplied nutrient absorbed into tissue) and internal allocation patterns.

Chemical speciation modeling (e.g., using ECOSAT) reveals that while macro-elements (N, K, Mg) exist predominantly as dissolved, bioavailable free ions (> 90%), transition metals like Fe and Cu exist mostly as chelated complexes (> 97% Fe-EDTA). Plants modify this speciation during culture through proton extrusion, organic acid exudation, and reductive cleavage.

Biotechnological Interventions and Genetic Engineering

Genetic Manipulation of Transporters for Enhanced NUE

Improving Nutrient Use Efficiency (NUE) without compromising crop yield is a primary objective as arable land decreases and fertilizer costs rise. Plant plasma membranes

house hundreds of transporter isoforms categorized into two kinetic systems:

- **Low-Affinity Transport Systems (LATS):** Operate primarily when external nutrient concentrations are high (millimolar range) via high-capacity channels or carriers.
- **High-Affinity Transport Systems (HATS):** Operate at low external concentrations (micromolar range) through inducible, proton-coupled symporters driven by proton gradients.

Nitrogen Transporter Families (NRT & AMT)

Nitrate uptake is managed by the NPF (NRT1) and NRT2 families. While NPF members were traditionally classified as low-affinity, AtNRT1.1 operates as a dual-affinity transceptor. NRT2 transporters act strictly in the high-affinity range and require accessory proteins (like NAR2) for proper membrane targeting. Ammonium uptake in acidic or waterlogged soils is mediated by the AMT family (e.g., AtAMT1;1, AtAMT1;3).

Overexpressing NRT2 and AMT1 transporters using root-specific promoters (such as RCc3 in rice) enhances root biomass, speeds up nitrogen assimilation, and maintains growth under low-input conditions. Modulating master transcription factors like NLP7 further coordinates the expression of broad nitrogen-responsive gene networks.

Phosphate Transporter Families (PHT)

Plants manage phosphorus dynamics across five localized families:

1. **PHT1:** Plasma membrane high-affinity P_i/H^+ symporters responsible for primary root uptake.
2. **PHT2:** Expressed in green tissues for chloroplast phosphate transport.
3. **PHT3:** Located in the inner mitochondrial membrane.
4. **PHT4:** Localized to the Golgi apparatus and plastids.
5. **PHT5:** Tonoplast-localized transporters handling vacuolar phosphate storage and release.

The ZIP Family and Micronutrient Biofortification

The ZIP family serves as the primary entry point for divalent transition metals like zinc (Zn^{2+}), iron (Fe^{2+}), and manganese (Mn^{2+}). While IRT1 acts as the principal iron uptake transporter under deficiency, its broad specificity creates an entry route for toxic heavy metals like cadmium (Cd^{2+}).

Biotechnologists address this by pairing ZIP overexpression with endosperm-specific promoters (e.g., rice glutelin or globulin promoters) to direct metal accumulation straight into edible grains. Co-expressing ZIP transporters with nicotianamine synthase (NAS) produces nicotianamine ligands that solubilize metals and improve phloem transport into developing seeds. Advanced protein engineering and CRISPR-Cas mutagenesis are now being used to alter ZIP binding pockets to block cadmium uptake while preserving iron and zinc entry.

Table 2. Target Transporter Families in Crop Biotechnology

Transporter Family	Primary Substrates	Key Physiological Role	Biotechnological Outcome
NRT / NPF	Nitrate, Peptides	Soil scavenging, systemic nitrate sensing	Enhanced Nitrogen Use Efficiency (NUE) under low-input farming.
AMT	Ammonium	High-affinity ammonium uptake in acidic/flooded soils	Improved early seedling vigour and nitrogen assimilation.
PHT (PHT1)	Inorganic Phosphate	Root epidermis acquisition and mycorrhizal symbiosis	Superior phosphorus capture, reduced rock phosphate dependence.
ZIP	Zinc, Iron, Manganese	Divalent cation uptake from rhizosphere	Biofortification of staple grains against micronutrient malnutrition.

1.2 Agronomic and Molecular Biofortification

Micronutrient malnutrition ("hidden hunger") affects over two billion people globally, primarily in regions relying on staple grains naturally low in bioavailable iron and zinc. While agronomic biofortification relies on soil or foliar fertilizer sprays, it is limited by ongoing costs and soil chemistry. Molecular biofortification offers a permanent biological solution through genetic modifications.

Endosperm-Specific Ferritin Expression

Milling strips away the mineral-rich aleurone layer of cereal grains, leaving white rice endosperm with low iron levels (< 2 mg kg^{-1}). Ferritin is an iron-storage protein capable of holding up to 4,500 iron atoms in a bioavailable ferric oxyhydroxide phosphate core. Expressing

ferritin genes (e.g., soybean *SoyFER1*) under endosperm-specific promoters (*GluB-1*, *Glb-1*) confines iron storage to the edible grain. Stacking ferritin expression with *NAS* (e.g., *OsNAS3*) boosts iron levels in polished rice grains to over 15 mg kg^{-1}—a 7- to 8-fold increase over wild-type levels.

Phytosiderophore Engineering for Calcareous Soils

In alkaline and calcareous soils (pH > 7.5), iron precipitates into insoluble oxides. Strategy II grasses secrete phytosiderophores of the mugineic acid (MA) family to chelate this insoluble Fe^{3+}. By introducing genes for key biosynthetic enzymes—such as NAS, NAAT, and DMAS—from efficient species like barley into crops like rice, scientists enhance phytosiderophore secretion. Transgenic rice expressing these pathways effectively solubilizes soil iron, preventing iron chlorosis and maintaining high yield in calcareous soils.

Overcoming Anti-Nutrients

Phytic acid stores phosphorus in seeds but binds strongly to cations (Fe^{2+}, Zn^{2+}, Ca^{2+}) to form indigestible phytate salts. To overcome this:

- **Low-Phytic Acid (*lpa*) Mutants:** Reduce phytic acid synthesis, though extreme reductions require balancing to protect seed germination.
- **Targeted Phytase Expression:** Endosperm-specific expression of microbial phytases (e.g., from *Aspergillus fumigatus*) keeps the enzyme inactive during storage. Upon consumption and hydration, the phytase rapidly breaks down phytic acid to release bound minerals for human absorption.

Table 3: Summary of Molecular Biofortification Strategies

Strategy	Target Element	Key Genes Involved	Primary Mechanism	Agronomic / Nutritional Benefit
Ferritin Overexpression	Iron (Fe)	*SoyFER1*, *Phaseolus vulgaris* ferritin	Iron storage within protein shells in the endosperm	Multiplies total iron concentration in polished edible grains.

Nicotianamine Synthase (NAS)	Iron (Fe), Zinc (Zn)	*OsNAS1*, *OsNAS2*, *OsNAS3*	Enhanced synthesis of metal-chelating nicotianamine	Improves internal phloem loading and long-distance transport to seeds.
Phytosiderophore Engineering	Iron (Fe)	*NAS*, *NAAT*, *DMAS*	Biosynthesis and root secretion of mugineic acids	Solubilises precipitated iron in alkaline and calcareous soils.
Phytase Co-Expression	Bioavailability	*Freq-phytase* (microbial)	Enzymatic degradation of phytic acid (anti-nutrient)	Releases chelated minerals for human digestive absorption.

Modern Innovations and Nanotechnology

Precision Genome Editing (CRISPR-Cas9)

- **Potassium & Nitrogen Uptake:** Disruption of *OsHAK8* in rice established its key role in K^+ translocation under stress. Editing *OsNPF3.1* alleles improved nitrogen utilization efficiency and yield.

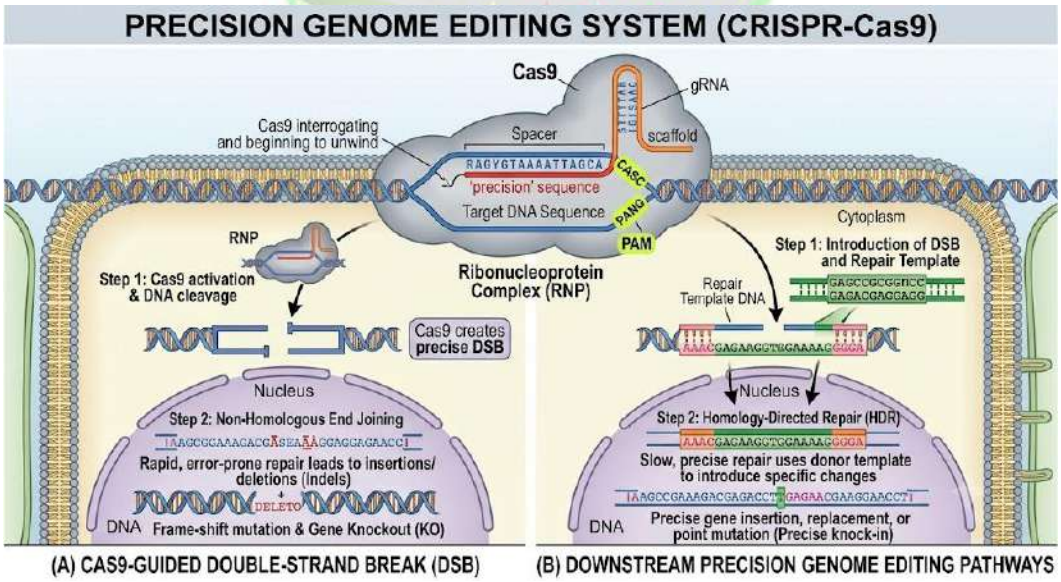


Figure 8. Precision genome editing system.

Root Architecture & Seed Quality: Knocking out *RRS1* enhanced lateral root branching and drought resilience in rice. Targeted edits to *TaIPK1* and *TaMADS29* in wheat reduced phytic acid and boosted grain density

Genomic Biofortification

Co-expressing soybean Ferritin, *Arabidopsis* AtIRT1/AtNAS1, and *Aspergillus fumigatus* Phytase in rice achieved a 4.5- to 5.3-fold increase in polished grain iron with improved bioavailability. Genome-Wide Association Studies (GWAS) and Marker-Assisted Selection (MAS) have mapped loci like *Gpc-B1* in wheat and *qZn5.1*/*OsZIP6* in rice, enabling breeding initiatives like HarvestPlus to release over 400 biofortified crop varieties globally.

Agricultural Nanotechnology

- **Targeted Delivery:** Foliar application and seed priming using Zinc Oxide (ZnO) nanoparticles improve photosynthetic pigment stability and crop yield under drought and salinity.
- **Structural & Stress Support:** Silica (SiO_2) nanoparticles strengthen cell wall architecture and upregulate AsA-GSH cycle genes (*TaMDHAR*, *TaDHAR*).
- **ROS Scavenging:** Magnesium-doped carbon dots and selenium nanoparticles (Se-NPs) scavenge ROS, limit electrolyte leakage, and turn on stress-responsive transcription factors under osmotic stress.

Conclusion and Future Perspectives

Unraveling the molecular framework of plant mineral nutrition—from dual-affinity transceptors (NRT1.1) and PHR1-SPX modules to CBL-CIPK/CPK calcium networks—has reshaped crop science. Combining these mechanisms with CRISPR-Cas9, biofortification strategies, and nano-fertilizers offers a clear pathway toward sustainable global agriculture.

Key priorities for future research include:

1. **Single-Cell Mapping:** Mapping hormone-ROS-Ca^{2+} cross-talk across root zones at single-cell resolution during combined nutrient stresses.
2. **Field Validation:** Testing the long-term stability and yield performance of CRISPR-edited NUE traits in variable field conditions.
3. **Nano-Ecotoxicology:** Evaluating the long-term ecological impact of engineered nanomaterials on soil health and beneficial rhizosphere microbiomes.

References

1. Alejandro, S., Höller, S., Meier, B., and Peiter, E. (2020). Manganese in plants: From acquisition to subcellular allocation. *Front. Plant Sci.* 11:300.
2. Alvarez, J.M., Schinke, A.L., Brooks, M.D., et al. (2020). Transient genome-wide interactions of the master transcription factor NLP7 initiate a rapid nitrogen-response cascade. *Nat. Commun.* 11:1157.
3. Bai, Q., Shen, Y., and Huang, Y. (2021). Advances in mineral nutrition transport and signal transduction in Rosaceae fruit quality and postharvest storage. *Front. Plant Sci.* 12:620018.
4. Chiou, T.J., and Lin, S.I. (2011). Signaling network in sensing phosphate availability in plants. *Annu. Rev. Plant Biol.* 62:185-206.
5. Dubeaux, G., Neveu, J., Zelazny, E., and Vert, G. (2018). Metal sensing by the IRT1 transporter-receptor orchestrates its own degradation and plant metal nutrition. *Mol. Cell* 69:953-964.
6. Fu, D., Zhang, Z., Wallrad, L., et al. (2022). Ca2+-dependent phosphorylation of NRAMP1 by CPK21 and CPK23 facilitates manganese uptake and homeostasis in Arabidopsis. *Proc. Natl. Acad. Sci. USA* 119:e2204574119.
7. Holst, A., Viñas, M., Méndez, J.C., Solórzano-Cascante, P., Guevara, E., and Jiménez, V.M. (2026). Nutrients uptake and chemical speciation reveal species-specific mineral nutrition patterns in four plant species in vitro. *Plant Cell, Tissue and Organ Culture (PCTOC)* 162:26.
8. Ju, C., Zhang, Z., Deng, J., et al. (2022). Ca2+-dependent successive phosphorylation of vacuolar transporter MTP8 by CBL2/3-CIPK3/9/26 and CPK5 is critical for manganese homeostasis in Arabidopsis. *Mol. Plant* 15:419-437.
9. Khan, M.I.R., Nazir, F., Maheshwari, C., Chopra, P., Chhillar, H., and Sreenivasulu, N. (2023). Mineral nutrients in plants under changing environments: A road to future food and nutrition security. *Plant Genome* 16:e20362.
10. López-Arredondo, D.L., Leyva-González, M.A., Alatorre-Cobos, F., and Herrera-Estrella, L. (2013). Biotechnology of nutrient uptake and assimilation in plants. *Int. J. Dev. Biol.* 57:595-610.
11. Puga, M.I., Rojas-Triana, M., de Lorenzo, L., et al. (2014). Novel signals in the

regulation of Pi starvation responses in plants: facts and promises. *Curr. Opin. Plant Biol.* 21:105-111.

12. Tang, R.J., Zhao, F.G., Yang, Y., et al. (2020). A calcium signalling network activates vacuolar K+ remobilization to enable plant adaptation to low-K+ environments. *Nat. Plants* 6:384-393.
13. Thakur, P.P., Jadhav, P.V., Dasgupta, D., et al. (2025). Mineral nutrient acquisition under stress: Sensing, signaling, and transportation. *Plant Science* 360:112702.

Volume: 06 Issue No: 09

FROST: ITS CAUSES, TYPES, PLANT PROTECTION MEASURES

Article ID: AG-V06-I09-49

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture, SKNAU,

Jobner, Rajasthan-303329, India

Introduction

Frost is a weather condition in which the temperature of plant tissues or the surrounding surface falls to approximately 0°C or below, causing water to freeze as ice crystals on plant surfaces or within plant tissues. Frost is an important abiotic stress that can severely damage crops, particularly during flowering, fruit set and early growth. Frost injury is especially important in fruit crops, vegetables, pulses, cereals and young seedlings.

Types of Frost: Frost can be classified according to its formation and environmental conditions.

A. Radiation Frost

- Occurs mainly on **clear, calm nights**.
- The ground loses heat rapidly by radiation.
- Air near the ground becomes cold.
- Common in valleys and low-lying areas.
- Also called **ground frost** or **black frost under some conditions when no visible ice forms**.

B. Advective Frost

- Occurs when a mass of **very cold air moves into an area**.
- Usually accompanied by cold winds.
- Can affect a large geographical region.
- More difficult to control than radiation frost.

C. Advection–Radiation Frost

- Combination of cold-air movement and night-time radiational cooling.

- Can produce severe frost injury.

D. Hoar Frost

- Water vapour changes directly into **ice crystals** on plant and soil surfaces.
- Usually produces a visible white frost.

E. Black Frost

- Temperature falls below freezing but the air is relatively dry.
- Little or no visible ice develops on plant surfaces.
- Plant tissues may become dark or black after injury.

F. White Frost

- Visible ice crystals form on plant surfaces.
- It is generally associated with high humidity and condensation followed by freezing.

Causes of Frost

Major causes include:

1. **Clear sky** – increases loss of heat from the soil and plants.
2. **Calm or low wind conditions** – allow cold air to accumulate near the ground.
3. **Low night temperature** – reduces plant tissue temperature below the freezing point.
4. **Cold air movement** – causes advective frost.
5. **Low atmospheric humidity** – increases radiational cooling.
6. **Dry soil** – stores less heat than moist soil.
7. **Low-lying topography** – cold air flows downward and accumulates in depressions.
8. **Early or late-season cold waves** – expose crops to freezing temperatures outside their normal tolerance period.
9. **Sudden temperature drops** – particularly dangerous to actively growing plants.
10. **Cloudless winter nights** – promote rapid heat loss from the soil surface.

Mechanism of Frost Injury: Frost injury occurs through several physiological and cellular processes.

Step 1: Cooling of Plant Tissue: When air temperature falls, plant tissues gradually lose heat.

Step 2: Formation of Ice: When tissue temperature falls below its freezing point, ice crystals may form. Ice generally develops first in **extracellular spaces**.

Step 3: Water Movement: Formation of extracellular ice lowers the water potential outside cells. Water moves out of the cells toward the growing ice crystals.

Step 4: Cellular Dehydration: Loss of water causes **cellular dehydration**, membrane shrinkage and disruption of normal cellular functions.

Step 5: Membrane Damage: Freezing and thawing can damage cell membranes. Membrane lipids and proteins may lose their normal organization, resulting in leakage of cellular contents.

Step 6: Intracellular Freezing: If cooling is sufficiently rapid or severe, ice may form inside cells. **Intracellular ice formation is usually lethal** because ice crystals physically damage cellular structures.

Step 7: Thawing Injury: Rapid thawing may cause additional membrane damage and leakage of electrolytes.

Major physiological effects

- Reduced photosynthesis
- Reduced respiration efficiency
- Membrane leakage
- Reduced water uptake
- Enzyme dysfunction
- Oxidative stress and ROS production
- Tissue necrosis
- Flower and fruit drop
- Reduced growth and yield

Classification of Plants According to Frost Resistance: Plants can broadly be classified into frost-resistant, frost-tolerant and frost-susceptible plants.

A. Frost-Resistant Plants: These plants can survive relatively low temperatures and short periods of freezing with limited injury.

Examples: Wheat, Barley, Oat, Rye, Pea, Mustard, Spinach, Kale, Carrot and Radish

Characteristics

- Better cold acclimation
- Greater ability to tolerate cellular dehydration
- Higher concentration of protective solutes
- More stable cell membranes
- Better antioxidant protection

B. Frost-Tolerant / Moderately Frost-Tolerant Plants

These plants can withstand **mild or short-duration frost**, but severe or prolonged frost causes injury.

Examples: Potato, Chickpea, Lentil, Onion, Cabbage, Cauliflower, Some citrus species and cultivars and Some temperate fruit crops during dormant stages

Their tolerance varies considerably with **cultivar, developmental stage and duration of cold exposure**.

C. Frost-Susceptible Plants

These plants are easily injured or killed by temperatures near or below freezing.

Examples: Tomato, Brinjal/eggplant, Chilli, Okra, Cucumber, Muskmelon, Watermelon, Papaya Banana, Many tropical and subtropical crops

Young seedlings, flowers and newly developing fruits are generally more susceptible than mature vegetative tissues.

Factors Affecting Frost Injury: The severity of frost injury depends on:

1. Temperature: Lower temperatures generally produce more severe injury.

2. Duration of Exposure: Longer exposure to freezing temperatures increases damage.

3. Rate of Cooling: Rapid cooling can cause greater injury than gradual cooling.

4. Plant Developmental Stage: Flowering and fruit-setting stages are often highly sensitive.

5. Plant Species and Variety: Different species and cultivars have different freezing tolerances.

6. Plant Water Status: Well-hydrated plants may respond differently from severely drought-stressed plants.

7. Soil Moisture: Moist soil generally stores more heat than dry soil.

8. Topography: Low-lying fields are more vulnerable because cold air accumulates there.

Mitigation of Frost: Frost management aims to **prevent plant temperature from falling below the critical injury temperature**.

A. Orchard and Field Management

1. Irrigation:

- Apply irrigation before a predicted radiation frost when appropriate.
- Moist soil stores more heat during the day and releases it at night.
- **Sprinkler irrigation** can protect crops during freezing conditions because freezing water releases latent heat.

- Continuous overhead sprinkler protection requires adequate water and correct application rates.

2. Smoke/Fog

Traditional smoke generation has limited effectiveness. Creating a dense smoke layer does **not reliably prevent frost** and is generally inferior to better frost-management methods.

3. Wind Machines

- Mix warmer air above the inversion layer with colder air near the surface.
- Particularly useful against **radiation frost**.
- Less effective during strong advective freezes when the entire air column is cold.

4. Orchard Heaters

- Heaters provide additional heat.
- Can reduce the rate of temperature decline.
- More effective when properly distributed throughout an orchard.

5. Frost Covers

- Use straw, cloth, plastic or suitable agricultural frost covers for small plants.
- Covers reduce heat loss from plant surfaces.
- Covers should be properly secured and removed or ventilated when temperatures rise.

6. Mulching: Organic mulch can influence soil temperature and reduce rapid temperature fluctuations. However, during a radiation frost, **bare, moist soil can sometimes release more stored heat at night than heavily insulated soil**, so mulch should be used according to the crop and frost-management objective.

7. Site Selection: Avoid planting highly frost-sensitive crops in:

- Depressions Valleys where cold air accumulates Poorly drained lowlands

Prefer **slightly elevated and well-drained locations** where appropriate.

8. Crop Selection

Use of varieties:

- Frost-resistant varieties
- Early- or late-flowering cultivars where appropriate
- Suitable rootstocks
- Crops adapted to the local climate

B. Cultural Practices

1. Maintain adequate soil moisture before frost.
2. Avoid excessive nitrogen application late in the season because it may encourage tender growth.
3. Maintain healthy plants through balanced nutrition.
4. Use appropriate planting dates to avoid critical growth stages during expected frost periods.
5. Maintain good weed control where weeds interfere with heat exchange.
6. Use windbreaks carefully; their effect depends on frost type and site conditions.
7. Harden seedlings before transplanting where applicable.

C. Chemical and Physiological Approaches: Some treatments have been investigated for improving cold or frost tolerance, including:

- **Potassium** Calcium
- Salicylic acid Brassinosteroids
- Abscisic acid-related treatments Antioxidant treatments
- Certain biostimulants

However, their effectiveness is **crop-, dose- and timing-dependent**, and they should not be considered substitutes for reliable physical frost-protection methods.

Important Frost Protection Methods at a Glance

Method	Main principle	Best suited for
Irrigation	Adds/stores heat and can release latent heat	Radiation frost
Sprinkler irrigation	Releases heat during freezing	Radiation frost
Wind machine	Mixes warmer upper air downward	Radiation frost
Orchard heaters	Adds heat	Orchards
Frost covers	Reduces heat loss	Vegetables, seedlings
Proper site selection	Avoids cold-air accumulation	Orchards/fields
Suitable planting date	Avoids sensitive stages	All crops
Resistant varieties	Increases inherent tolerance	All crops

Symptoms: Common symptoms include:

- Water-soaked appearance of tissues Leaf wilting
- Leaf curling Browning or blackening of leaves
- Necrosis of growing points Stem cracking or splitting
- Flower abortion Fruit drop
- Poor fruit set Reduced shoot growth
- Death of young seedlings Internal browning or tissue discoloration

Economic Importance of Frost Damage: Frost can cause substantial agricultural losses through:

- Destruction of seedlings Reduced flowering Poor fruit set Fruit drop
- Reduced crop yield Reduced fruit quality Damage to perennial fruit trees
- Increased cost of crop protection Loss of farmer income

Frost protection is therefore particularly important in fruit-growing regions and areas where winter temperature frequently approaches freezing.

Summary: Frost is an important abiotic stress caused by freezing or near-freezing temperatures. It can occur mainly as radiation frost, advective frost or a combination of both. Frost causes injury primarily through ice formation, cellular dehydration, membrane disruption, oxidative stress and, under severe conditions, intracellular freezing. Plants differ greatly in their frost resistance. Wheat, barley, rye, pea and many cool-season crops generally possess greater frost tolerance, whereas tomato, chilli, brinjal, cucumber, papaya and banana are highly frost susceptible. The severity of injury depends on temperature, duration, cooling rate, crop species, variety and developmental stage. Effective frost management includes proper site and planting-date selection, adequate soil moisture, sprinkler irrigation, wind machines, orchard heaters, protective covers and frost-tolerant varieties. An integrated approach is generally the most effective strategy for minimizing frost-induced crop losses

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

UTILIZATION OF MIXTALOL FOR BETTER PRODUCTION IN ARID ZONE FRUIT PLANTS

Article ID: AG-VO6-I09-50

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture, SKNAU,

Jobner -303329, Rajasthan India

Introduction

Mixtalol is a plant growth-promoting substance associated with the group of long-chain aliphatic alcohols, commonly studied in relation to growth regulators such as triacontanol. These compounds have been investigated for their potential to improve plant growth, photosynthetic activity, nutrient utilization and crop productivity. In arid and semi-arid regions, fruit plants are frequently exposed to high temperatures, drought, poor soil fertility and moisture stress. Plant growth-promoting substances may help improve physiological activity and productivity when used appropriately along with irrigation, nutrition and other orchard management practices.

Important terminology note:

The name *Mixtalol* (also written as Maxtalol or Mixtalot) is not a consistently standardized scientific name for a single plant growth regulator. It may refer to a commercial formulation or a mixture of long-chain alcohols. Its exact composition should be confirmed from the product label. The following notes describe its potential use as a growth-promoting long-chain alcohol formulation, not as a universally validated treatment for all fruit crops.

Classification of Mixtalol:

Mixtalol is generally described in agricultural literature as a triacontanol-based growth regulator containing a mixture of long-chain aliphatic alcohols, approximately C24–C34.

It can be classified in the following ways:

Classification basis	Description
Chemical nature	Mixture of long-chain aliphatic alcohols

Classification basis	Description
Growth-regulator group	Triacontanol-based plant growth promoter
Formulation	Commercial growth-regulator formulation; composition depends on the product
Application	Primarily investigated as a foliar-applied growth promoter

Mixtalol is not a separate plant hormone class like auxins, gibberellins or cytokinins. Its classification is based on its chemical composition and commercial formulation.

Importance of Mixtalol in arid-zone fruit plants: Arid-zone fruit crops such as ber, pomegranate, aonla, date palm, bael, fig and lasoda are cultivated under challenging environmental conditions.

Mixtalol may have potential importance in these crops through the following physiological effects:

1. **Improvement in photosynthesis:** May promote photosynthetic activity and the accumulation of carbohydrates.
2. **Enhanced vegetative growth:** May support leaf expansion, shoot growth and biomass production.
3. **Improved nutrient utilization:** May support nutrient uptake and metabolic activity.
4. **Potential stress mitigation:** May contribute to maintaining physiological activity under some stress conditions, although drought protection in arid fruit trees is not established.
5. **Fruit productivity:** Improved source-leaf activity could potentially support fruit growth, fruit size and yield when other limiting factors are adequately managed.

These are potential benefits based on general growth-regulator research, not confirmed responses in every arid-zone fruit species.

Mechanism of action of Mixtalol in arid-zone fruit plants: Mixtalol is not considered a conventional plant hormone with a fully established receptor-mediated mechanism. Its reported growth-promoting effects are associated with changes in plant physiological and biochemical processes.

Major physiological processes

- **Photosynthesis:** Mixtalol has been associated with increased photosynthetic activity in some crop studies. Greater carbon assimilation may support vegetative growth and fruit development.
- **Carbohydrate metabolism:** Changes in sugar metabolism may contribute to the supply of assimilates for developing fruits.
- **Protein synthesis and metabolism:** Growth-regulator studies have reported changes in protein content and other metabolic parameters.
- **Water relations and stress response:** Some growth-regulator studies suggest improved physiological performance under stress. However, Mixtalol should not be assumed to reduce water loss or confer drought tolerance in fruit trees without crop-specific evidence.

The magnitude of these responses depends on species, cultivar, plant age, dose, application stage and environmental conditions.

Practical utility of Mixtalol in arid-zone fruit plants: Mixtalol could be investigated as a supplementary growth-promoting treatment in arid horticulture.

Fruit crop	**Potential area of investigation**
Ber ((Ziziphus mauritiana)	Shoot growth, leaf activity and fruit development
Pomegranate	Canopy growth, fruit growth and yield
Aonla (Phyllanthus emblica)	Vegetative growth and fruit development
Date palm	Leaf physiological activity and fruit development
Bael (Aegle marmelos)	Vegetative growth and fruit development
Fig (Ficus carica)	Shoot growth and fruit size

These are suggested research applications rather than established crop-specific recommendations.

Effective concentration of Mixtalol in arid-zone fruit plants:

There is no sufficiently verified, universally recommended Mixtalol concentration for ber, pomegranate, aonla, date palm, bael or other arid-zone fruit crops. Concentrations reported for other crops should not automatically be adopted for fruit trees.

Concentrations reported in related crop research

Crop / research context	Reported conc.	Application
Brinjal, tomato, bottle gourd and squash	2–4 ppm	One spray at flowering, 4–6 weeks after planting
Onion	2–4 ppm	Spray during early bulb growth
Wheat under salinity-related research	750 mg/L (750 ppm)	Reported in a pre-sowing treatment study

Important concentration conversion

For dilute aqueous solutions:

- 1 ppm ≈ 1 mg/L
- 2 ppm ≈ 2 mg/L
- 4 ppm ≈ 4 mg/L

For a commercial formulation, the required product quantity depends on its active-ingredient content. The concentration of the active ingredient should not be confused with the concentration of the commercial product.

Role of Mixtalol in the national economy: Mixtalol may have an indirect economic role in Indian horticulture if crop-specific research demonstrates that it improves yield or fruit quality economically.

Potential contributions include:

1. **Increased orchard productivity:** A verified yield response could increase farmers' returns per unit area.
2. **Improved fruit quality:** Better fruit size or quality, if demonstrated, could improve marketability and value.
3. **Support for arid-region horticulture:** Fruit crops adapted to dry regions contribute to farm diversification and rural livelihoods.
4. **Employment generation:** Profitable fruit production can support orchard management, harvesting, grading, processing and marketing.
5. **Research and technology development:** Testing growth regulators under arid conditions may contribute to locally appropriate horticultural recommendations.

Economic caution: These benefits are conditional. There is insufficient crop-specific evidence to quantify the national economic contribution of Mixtalol itself. Any economic assessment should consider additional yield, fruit price, product cost, labour and application expenses.

Summary: Mixtalol is a triacontanol-based growth-promoting formulation associated with a mixture of long-chain aliphatic alcohols. It has been investigated for its effects on plant growth, photosynthesis, metabolism and crop productivity. In arid-zone fruit plants, including ber, pomegranate, aonla, date palm, bael and fig, Mixtalol may have potential as a supplementary growth regulator. However, its effectiveness under arid conditions, its role in drought tolerance, and its effects on fruit yield and quality require further crop-specific research. Although concentrations of 2–4 ppm have been reported in vegetable crops, these cannot be treated as established recommendations for arid fruit trees. Appropriate concentrations, application timing and economic benefits must be determined through replicated field trials and verified product-label guidance. In conclusion, Mixtalol is a potential research tool for improving fruit-tree productivity, but it should not be considered a proven drought-management treatment or a universally recommended growth regulator for arid-zone fruit crops.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article on Auxin.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

OILSEEDS FOR A SUSTAINABLE FUTURE: SEEDS OF FOOD SECURITY AND PROSPERITY

Article ID: AG-V06-I09-51

C. Selvakumar[1]*, C. Kalaiyarasan[2] and K. Balagangathar[3]

[1]PG Scholar, [2]Associate Professor, [3]Phd Scholar, Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar – 608 002, Tamil Nadu, India.

*Corresponding Author: C. Selvakumar

Abstract

Oilseed crops occupy a unique and expanding position in global and Indian agriculture, supplying edible oil, protein-rich meal, and industrial raw material while anchoring the livelihoods of millions of smallholder farmers. As the world confronts the combined pressures of population growth, changing dietary patterns, and climate change, oilseeds have emerged as strategic crops capable of simultaneously advancing food security, nutritional security, rural incomes, and environmental sustainability. Global production of soybean, rapeseed-mustard, groundnut, sunflower, sesame, safflower, and other oilseeds continues to expand, yet yield gaps, import dependence, and climatic vulnerability constrain their full potential in many developing economies, including India. India, despite ranking among the largest oilseed-growing countries, imports more than half of its edible oil requirement, prompting renewed policy emphasis on domestic production through missions such as the National Mission on Edible Oils. This review examines the global and Indian oilseed scenario, the contribution of oilseeds to food and nutritional security and farmer prosperity, and the impact of climate change on production stability. It further discusses sustainable intensification strategies, including integrated nutrient and water management, integrated pest management, and organic and regenerative approaches, alongside emerging tools such as precision and digital agriculture, biotechnology, and genome editing that are reshaping oilseed breeding and management. The oilseed value chain, its by-products, and their role in a circular bioeconomy are explored, followed by a critical assessment of existing challenges and future opportunities. The review concludes that an integrated approach

combining improved varieties, resource-efficient agronomy, digital technologies, and stronger market and institutional support is essential for building a resilient, self-reliant, and sustainable oilseed sector.

Keywords: Oilseeds, Food Security, Sustainable Agriculture, Climate Resilience, Precision Agriculture, Farmer Prosperity.

Introduction

Oilseed crops rank among the most economically and nutritionally important agricultural commodities in the world. Species such as soybean, rapeseed-mustard, groundnut, sunflower, sesame, safflower, linseed, and castor supply the vegetable oils that dominate global diets, along with protein-rich cakes and meals that sustain the livestock and aquaculture industries. Beyond their direct food value, oilseeds are indispensable to industrial sectors ranging from biodiesel and oleochemicals to cosmetics and lubricants, making them a pillar of both food and industrial economies. The importance of oilseeds extends well beyond nutrition. For millions of smallholder farmers across Asia, Africa, and Latin America, oilseed cultivation is a primary source of cash income, particularly in rainfed and marginal environments where cereal cultivation alone cannot guarantee livelihood security.

Oilseeds also fit naturally into diversified and resource-conserving cropping systems, often requiring less water than staple cereals while improving soil fertility through their inclusion in rotations with legumes and cereals. Despite this significance, global and Indian oilseed production continues to face structural challenges. Yield levels in most developing countries remain well below genetic potential owing to limited access to quality seed, inadequate nutrient and water management, and recurring losses from pests, diseases, and climatic extremes. Climate change compounds these constraints by intensifying heat stress, altering rainfall patterns, and expanding the geographic range of pests, thereby threatening the stability of oilseed-based food and income systems (Zhang *et al.,* 2023). Addressing these challenges requires a coordinated response that integrates improved genetics, precision and digital technologies, sustainable resource management, and strengthened value chains. This review synthesises current knowledge on the global and Indian oilseed scenario, examines the contribution of oilseeds to food security and farmer prosperity, and outlines pathways toward a resilient and sustainable oilseed future.

Global Oilseed Scenario

The global oilseed sector comprises a diverse range of crops, each adapted to specific agro-climatic conditions and contributing significantly to the world's food, feed, and industrial systems**. Soybean is the dominant oilseed in global production and trade**, driven by increasing demand for vegetable oil and protein-rich meal for livestock and poultry feed, particularly in Asia and Latin America. Rapeseed-mustard and sunflower are important temperate oilseeds cultivated widely in Europe, Canada, and parts of Asia, while groundnut, sesame, and castor are extensively grown in tropical and subtropical regions, including India, China, and West Africa. Together, these crops occupy a considerable proportion of global agricultural land and contribute substantially to international agricultural trade.

Global production of oilseeds and vegetable oils has continued to increase, supported by improvements in crop productivity, expansion of cultivated areas, particularly in South America, and growing demand from emerging economies. However, the sector is increasingly influenced by environmental concerns, particularly those associated with deforestation and sustainable production practices. Climate variability, geopolitical disturbances, changing trade policies, and fluctuations in input costs also create uncertainty in oilseed production and international markets. These challenges highlight the importance of developing **diversified, sustainable, and climate-resilient oilseed production systems** to ensure stable supplies and meet the growing global demand for edible oils and plant-based protein.

Indian Oilseed Scenario and the Path to Self-Reliance

India is one of the world's major oilseed-producing countries, cultivating nine principal oilseed crops, including groundnut, soybean, rapeseed-mustard, sunflower, sesame, safflower, niger, castor, and linseed. Oilseeds occupy about 14% of the gross cropped area and play an important role in food security, farm income, and agricultural trade. Major oilseed-producing states include Rajasthan, Madhya Pradesh, Gujarat, Maharashtra, Uttar Pradesh, Karnataka, Andhra Pradesh, and Tamil Nadu.Despite its large production base, India remains significantly dependent on imported edible oils. The National Mission on Edible Oils-Oilseeds (NMEO-Oilseeds) aims to strengthen domestic production and reduce import dependence through improved varieties, better agronomic practices, higher productivity, and technological adoption. Achieving Atmanirbharta in edible oils will require closing yield gaps, promoting high-yielding and hybrid varieties, improving irrigation and extension services, strengthening farmer

institutions, and expanding oil extraction and processing infrastructure, particularly in rainfed areas.

Oilseeds and Food and Nutritional Security

Edible oils derived from oilseeds are a concentrated source of **dietary energy and essential fatty acids**, including omega-3 and omega-6 fatty acids that the human body cannot synthesise. Mustard and soybean oils provide favourable polyunsaturated fatty acids, while groundnut and sesame oils are valued for their **antioxidant content and oxidative stability**. Breeding efforts are also increasing **oleic acid** in sunflower, soybean, and rapeseed oils to improve nutritional quality. The **protein-rich cakes and meals** remaining after oil extraction are important for nutritional security. Soybean meal, groundnut cake, and mustard cake are widely used in **poultry, dairy, and aquaculture feeds**, supporting animal protein production. Whole oilseeds such as sesame and groundnut also provide **zinc, iron, and vitamin E**, contributing to dietary diversity and reducing hidden hunger.

Oilseeds and Farmer Prosperity

Oilseed crops provide important **income and employment opportunities for small and marginal farmers**, particularly in rainfed areas. Short-duration and drought-tolerant crops such as **groundnut, sesame, and mustard** support crop diversification and improve income stability. **Processing and value addition** create rural employment and increase farmers' share in the value chain. **Farmer Producer Organisations (FPOs)** help farmers access quality inputs, credit, collective marketing, and better prices. Strengthening **assured procurement, minimum support prices, and market linkages** is essential to make oilseed cultivation more profitable and encourage farmers to expand oilseed production.

Climate Change and Oilseed Production

Rising temperatures, erratic rainfall, drought, heat waves, and unseasonal rains pose major challenges to oilseed productivity. Heat stress during flowering and seed filling can reduce pollen viability and seed set, while excess moisture and waterlogging can damage crop establishment. Climate change may also increase pest and disease pressure by altering their distribution and survival. Climate resilience requires **drought- and heat-tolerant varieties, suitable sowing dates, conservation agriculture, improved water management, and crop diversification**. Intercropping and diversified sequences involving legumes with oilseeds such as

sesame and safflower can improve yield stability and water-use efficiency, particularly in rainfed areas (Kumari *et al.*, 2025).

Soil Health and Integrated Nutrient Management

Balanced fertilisation, combining nitrogen, phosphorus, and potassium with secondary and micronutrients such as sulphur, zinc, and boron, is essential for oilseed productivity and oil quality, since sulphur in particular is a direct constituent of oil biosynthesis pathways. Field research on groundnut-mustard cropping sequences has shown that optimised sulphur application, including through emerging sulphur nanoparticle formulations applied in split doses, significantly improves seed yield, nutrient uptake, and micronutrient availability compared with conventional fertiliser sources, while also enhancing residual soil sulphur fractions for the following crop (Yadav *et al.*, 2026). Complementing mineral fertilisers with farmyard manure, compost, vermicompost, and biofertilisers such as Rhizobium, phosphate-solubilising bacteria, and sulphur-oxidising bacteria further improves nutrient-use efficiency and long-term soil organic carbon status, reducing dependence on synthetic inputs over time.

Water Conservation and Efficient Irrigation

Most Indian oilseeds are grown under **rainfed conditions**, making efficient use of limited moisture essential for stable yields. Practices such as **mulching, in-situ moisture conservation through ridge-and-furrow or broad-bed-and-furrow systems, and supplemental irrigation at critical stages** improve water-use efficiency. Where irrigation is available, **drip and micro-sprinkler systems combined with soil moisture-based scheduling** reduce water use while sustaining yield. Diversified **legume–oilseed cropping systems with effective rainwater management** can further enhance productivity and water-use efficiency in semi-arid regions (Kumari *et al.*, 2025).

Integrated Pest and Disease Management

Insect pests such as aphids, whitefly, pod borers, and leaf miners, along with fungal and viral diseases including rust, blight, and yellow mosaic virus, cause substantial yield losses in oilseed crops each year. Integrated pest management combining resistant varieties, timely sowing, field sanitation, biological control agents, botanical extracts such as neem-based formulations, and judicious use of chemical pesticides only when economic thresholds are crossed offers a sustainable alternative to calendar-based spraying. Pheromone traps and

community-level pest monitoring further support early detection and coordinated management across contiguous fields, reducing overall pesticide load and associated costs.

Organic and Regenerative Approaches

Organic and regenerative practices, including reduced tillage, cover cropping, residue retention, and diversified rotations, enhance soil organic carbon, biological activity, and long-term resilience of oilseed cropping systems. While organic oilseed cultivation often involves a transitional yield penalty, it can command premium prices in niche and export markets, and its environmental co-benefits - improved soil structure, reduced input costs, and enhanced biodiversity make it an important complement, rather than a wholesale replacement, for conventional intensification strategies in appropriate contexts.

Precision and Digital Agriculture in Oilseed Production

Precision and digital technologies are transforming oilseed production by improving **input-use efficiency and site-specific decision-making**. Satellite imagery, UAVs with multispectral and thermal sensors, and AI-based models enable early detection of **nutrient deficiencies, water stress, pests, and diseases**, allowing targeted interventions. In soybean, hybrid deep-learning and evolutionary optimisation models using hyperspectral vegetation indices have accurately estimated **yield and fresh biomass before harvest** (Yoosefzadeh-Najafabadi *et al.*, 2021). These technologies also support **yield forecasting, variable-rate fertilisation, irrigation scheduling, and real-time farmer advisories**, while IoT-based sensors provide location-specific recommendations to oilseed farmers.

Biotechnology and Genome Editing for Improved Oilseeds

Conventional breeding, supported by **molecular markers and genomic selection**, continues to develop high-yielding, disease-resistant, and stress-tolerant oilseed varieties. **CRISPR/Cas9 genome editing** further enables precise improvement of oil quality, particularly through modification of fatty acid desaturase genes such as **FAD2 and FAD3**, which can increase oleic acid and improve oil stability. In field cress, CRISPR/Cas9 editing has successfully modified fatty acid composition for food and industrial uses (Sandgrind *et al.*, 2023). However, wider adoption requires addressing **regulatory challenges, local adaptation, breeding capacity, and access to genomic technologies**, particularly in developing countries (Vaikuntapu & Kumar, 2023).

Oilseed Value Chain, By-products, and the Circular Bioeconomy

The oilseed value chain includes **production, harvesting, storage, processing, oil extraction, packaging, and marketing**. Improving drying, storage, moisture testing, and organised procurement can reduce post-harvest losses and increase farmer income. Oil extraction also produces protein-rich **oil cakes and meals**, which can be utilised as animal feed, biofertilisers, functional food ingredients, and substrates for biogas and enzyme production. Integrated valorisation of these by-products can enhance processing profitability, reduce waste, and promote a **circular bioeconomy** (Grahovac *et al.*, 2025).

Challenges in Oilseed Production

Oilseed production faces **yield gaps, poor access to quality seed, rainfed dependence, and fragmented landholdings**, which increase production risks and limit mechanisation. Rising input and labour costs, **unstable prices and competition from imported edible oils** reduce farmer profitability. Inadequate storage and processing infrastructure causes post-harvest losses, while limited access to digital advisory services slows precision-agriculture adoption. Addressing these challenges requires **coordinated support in research, extension, infrastructure, technology, and market policies.**

Future Prospects

The future of oilseed agriculture depends on integrating **climate-resilient varieties, precision technologies, sustainable resource management, and strong market support**. Drought- and heat-tolerant varieties, genome editing, and AI-based yield forecasting can help reduce yield gaps. Efficient nutrient and water management, along with organic and regenerative practices, will support sustainable production. Strengthening **Farmer Producer Organisations (FPOs)**, assured procurement, processing facilities, and value addition of oilseed by-products will improve farmer income. With continued support through initiatives such as the **National Mission on Edible Oils-Oilseeds (NMEO-Oilseeds)**, India can move towards **edible-oil self-reliance and sustainable, farmer-centred agricultural growth.**

Conclusion

Oilseed crops are vital for **food security, nutrition, farmer livelihoods, and environmental sustainability.** Their future depends on integrating **climate-resilient varieties, precision agriculture, sustainable soil and water management, and biotechnology**, supported by strong farmer institutions and value chains. Addressing yield gaps, climate risks, and import

dependence through **coordinated research, infrastructure, and policy support** can build a **self-reliant, resilient, and profitable oilseed sector**. Strengthening **value addition, processing, and market linkages** can further enhance farmer income and reduce post-harvest losses. **Sustainable and farmer-centred development** will be essential for meeting the growing demand for edible oils in the future.

References

Grahovac, N., Aleksic, M., Trajkovska, B., Jeromela, A. M., & Nakov, G. (2025). Extraction and valorization of oilseed cakes for value-added food components - A review for a sustainable foodstuff production in a case process approach. Foods, 14(13), 2244.

Kumari, V. V., Gopinath, K. A., Chandran, M. A. S., Shankar, A. K., Suvana, S., Kumar, M., Raju, B. M. K., Jyothilakshmi, N., Santosh, S., Venkatesh, G., Sriram, K., Sunitha, B., Prasanna, G. K., Bag, S., Rao, M. S., & Singh, V. K. (2025). Diversified legume-oilseed cropping system for synergistic enhancement of yield and water use efficiency in rainfed areas of semi-arid tropics. *plos one*, 20(2), e0317373.

Sandgrind, S., Li, X., Ivarson, E., Wang, E. S., Guan, R., Kanagarajan, S., & Zhu, L. H. (2023). Improved fatty acid composition of field cress (Lepidium campestre) by CRISPR/Cas9-mediated genome editing. *Frontiers in Plant Science*, *14*, 1076704.

Vaikuntapu, P. R., & Kumar, V. D. (2023). Applications and challenges of harnessing genome editing in oilseed crops. *Journal of Plant Biochemistry and Biotechnology*, *32*, 751–772.

Yadav, S. L., Patel, K. C., Kumar, D., Jinger, D., Yadav, L. P., Birla, D., Yadav, M., Yadav, R. K., Yadav, I. R., Lakshman, Minkina, T., Rajput, V. D., Yadav, P., & Meena, V. S. (2026). Nanotechnology strategies for enhancing productivity, sulphur use efficiency and soil fertility in groundnut-mustard cropping systems. *Scientific Reports*, 16, Article 3170.

Yoosefzadeh-Najafabadi, M., Tulpan, D., & Eskandari, M. (2021). Using hybrid artificial intelligence and evolutionary optimization algorithms for estimating soybean yield and fresh biomass using hyperspectral vegetation indices. *Remote Sensing, 13*(13), 2555.

Zhang, H., Zhou, G., Varshney, R. K., & Wan, S. (2023). Editorial: Advances in plant cultivation and physiology of oilseed crops. *Frontiers in Plant Science*, 14, 1280392.

Volume: 06 Issue No: 09

CHANGING TEMPERATURES, CHANGING FISH: REPRODUCTION AND EARLY LIFE UNDER CLIMATE STRESS

Article ID: AG-V06-I09-52

M. Sharumathi

Department of Fisheries Biology and Resource Management

Fisheries College and Research Institute, Thoothukudi, Tamil Nadu, India

Abstract

Fish reproduction is not simply a matter of adults producing eggs and sperm. It is a carefully timed biological process linked to temperature, light, food availability and seasonal environmental change. Climate change is disturbing some of these cues. As waters warm and ocean carbon dioxide (CO_2) rises, the effects can reach from the reproductive organs of adult fish to the behaviour and survival of newly hatched larvae. The evidence comes from freshwater, marine and temperate and tropical species, showing that there is no single response shared by all fish. Instead, the outcome depends on the species, its normal thermal environment, the timing of warming and the life stage exposed.

Why temperature matters so much

Temperature is one of the fundamental environmental regulators of fish biology. It influences the development of gametes, maturation, spawning, embryonic development, hatching, larval growth and survival (Pankhurst & Porter, 2003; Pankhurst & King, 2010). A rise in spring temperature can help trigger maturation in spring-spawning fish. In contrast, unusually high temperatures later in the year can delay maturation or ovulation in species that normally spawn during cooler periods. Thus, climate change does not necessarily mean that every fish will simply 'stop reproducing'. It can shift the calendar of reproduction, shorten the spawning season, or—in sufficiently sensitive species, suppress reproduction altogether (Pankhurst & Munday, 2011). The sensitivity of fish also differs among thermal environments. Inhibitory effects at roughly 10–12°C in some cold-water species, around 18°C in Atlantic salmon and other cold-temperate fish, near 24°C in some temperate species, and around 30°C or above in several

tropical fishes (Pankhurst & Munday, 2011). These are examples rather than universal limits: the relevant temperature threshold varies from species to species.

Inside the fish: when warming reaches the reproductive system

Fish reproduction is coordinated by a hormonal communication network known as the hypothalamo–pituitary–gonadal (HPG) axis. In simple terms, the brain communicates with the pituitary gland, the pituitary releases reproductive hormones, and those hormones stimulate the gonads. Follicle-stimulating hormone (FSH) and luteinising hormone (LH) are especially important in gamete development and maturation (Planas & Swanson, 2008; Zohar et al., 2010). In females, oestrogen helps stimulate the liver to produce vitellogenin, a major precursor of egg yolk. Developing oocytes take up this material as they grow. Oestrogen also contributes to production of proteins that become part of the egg's protective envelope (Tyler et al., 2000; Babin et al., 2007). Because temperature can influence hormone production and enzyme activity, warming can therefore affect reproduction at a surprisingly early stage.

The aromatase connection

Aromatase, an enzyme involved in the production of estrogen. Elevated temperature has been associated with reduced aromatase activity in several fishes. In Atlantic salmon, for example, high temperature during important reproductive stages can reduce oestrogen production, vitellogenin production and egg development, with consequences for egg size, fertility and survival (Pankhurst & King, 2010). Similar temperature-related changes have been reported in red seabream and pejerrey (Lim et al., 2003; Soria et al., 2008).

Not all warming happens at the same time

Timing can be more important than the average temperature alone. Research on Atlantic salmon found that females were particularly sensitive to elevated temperature during a period of active oocyte growth and gonadal reorganisation (King et al., 2007). A heat event that occurs outside such a sensitive window may have a smaller reproductive effect than the same temperature during a critical developmental stage. Seasonal spawning strategies also matter. Tropical fishes living in the same region can have different spawning periods and different thermal thresholds. The spiny damselfish, Acanthochromis polyacanthus, shows reproductive inhibition above about 30°C, whereas the humbug dascyllus, Dascyllus aruanus, which spawns later when waters are naturally warmer, was reported to show inhibition at a higher temperature

(Donelson et al., 2010; Pankhurst & Munday, 2011). This illustrates why climate impacts must be assessed species by species.

Stress, food and age add another layer

Food availability and body condition can also change the outcome. Experiments with spiny damselfish found that good nutritional condition could provide some protection against temperature-related reproductive inhibition (Donelson et al., 2010). This means a warming ocean combined with reduced food supply could be more damaging than warming alone. Age structure may matter too. In Atlantic salmon, repeat-spawning females showed better fertility and egg survival than first-time spawners when exposed to elevated temperatures, suggesting that populations dominated by younger fish could be more vulnerable to thermal disruption.

From eggs to larvae: the most vulnerable beginning

A fish population can only replace itself if eggs survive, larvae develop successfully and enough young fish reach recruitment. Early life stages are often particularly sensitive to environmental change. Eggs can have narrow thermal tolerance windows, and small increases above suitable temperatures can sharply increase mortality in some species (Rombough, 1997; Gagliano et al., 2007).

Warmer water speeds development—but faster is not always better

Temperature strongly controls the speed of embryonic development. In many species, development can increase more than threefold for a 10°C increase in temperature, although the exact response depends on species and developmental stage (Rombough, 1997). As water warms, eggs can hatch sooner. This sounds beneficial, but early hatching can become a problem if the surrounding environment is not yet favourable for feeding, avoiding predators or finding suitable habitat. For some eggs, especially larger eggs and eggs of cold-water species, warming can shift hatching from hours to days. The ecological consequences depend on whether hatching remains synchronised with other environmental cues. In some fishes, non-temperature cues such as the day–night cycle may help keep hatching at an appropriate time even when embryos become physiologically ready earlier (Pauly & Pullin, 1988).

Larvae Live Fast—and Warming Makes Them Faster

Rising temperature generally speeds up larval metabolism and development, shortening the pelagic larval duration (PLD). A shorter larval period may reduce exposure to predators and

other hazards, but warmer water also increases food requirements. When food is limited, larvae may face higher starvation risk and reduced survival (O'Connor et al., 2007).

Recruitment: From Larvae to Fisheries

Recruitment—the successful addition of young fish to a population—is a critical link between climate and fisheries. Moderate warming may benefit some species, but prolonged or extreme warming can reduce larval supply and recruitment, particularly when ocean productivity and food availability decline (Lo-Yat et al., 2011). Even small changes in larval survival can have major consequences when repeated across an entire spawning population, affecting year-class strength, population structure and future fishery yields.

Every Species Responds Differently

Climate impacts are not the same for all fish. Species living close to their thermal limits may be more vulnerable than those with broader thermal ranges. Spawning timing, food availability, habitat, reproductive flexibility and previous thermal history can all influence their ability to cope with warming.

Five Priorities for the Future

- Monitor spawning seasons and reproductive timing.
- Monitor eggs and larvae, not only adult populations.
- Measure temperature alongside food and habitat conditions.
- Include behaviour and sensory responses in climate studies.
- Develop species- and location-specific knowledge rather than relying on universal thermal thresholds.

The Bigger Picture

The key message is that climate change will not affect every fish population in the same way. Moderate warming may accelerate larval development, while excessive or poorly timed warming can suppress reproduction, reduce egg and larval survival and make recruitment less predictable. For tropical coastal fisheries, long-term monitoring of temperature, gonadal development, spawning, fecundity, larval abundance and recruitment will be increasingly important. Ultimately, the future of a fish population begins long before the adult fish appears. A viable egg, successful embryo and surviving larva are the foundation of tomorrow's fishery.

References

Babin, P. J., Carnevali, O., Lubzens, E., & Schneider, W. J. (2007). Molecular aspects of oocyte vitellogenesis in fish. In P. J. Babin, J. Cerda & E. Lubzens (Eds.), The Fish Oocyte. Springer.

Donelson, J. M., Munday, P. L., McCormick, M. I., Pankhurst, N. W., & Pankhurst, P. M. (2010). Effects of elevated water temperature and food availability on the reproductive performance of a coral reef fish. Marine Ecology Progress Series, 401, 233–243. https://doi.org/10.3354/meps08366

Gagliano, M., McCormick, M. I., & Meekan, M. G. (2007). Temperature-induced shifts in selective pressure at a critical developmental transition. Oecologia, 152, 219–225. https://doi.org/10.1007/s00442-006-0647-1

King, H. R., Pankhurst, N. W., & Watts, M. (2007). Reproductive sensitivity to elevated water temperatures in female Atlantic salmon is heightened at certain stages of vitellogenesis. Journal of Fish Biology, 70, 190–205. https://doi.org/10.1111/j.1095-8649.2006.01295.x

Lim, B.-S., Kagawa, H., Gen, K., & Okuzawa, K. (2003). Effects of water temperature on gonadal development and expression of steroidogenic enzymes in juvenile red seabream. Fish Physiology and Biochemistry, 28, 161–162.

Lo-Yat, A., Meekan, M. G., Lecchini, D., Martinez, E., Galzin, R., et al. (2011). Extreme climatic events reduce ocean productivity and larval supply in a tropical reef ecosystem. Global Change Biology, 17, 1695–1702. https://doi.org/10.1111/j.1365-2486.2010.02355.x

O'Connor, M. I., Bruno, J. F., Gaines, S. D., Halpern, B. S., Lester, S. E., et al. (2007). Temperature control of larval dispersal and the implications for marine ecology, evolution, and conservation. Proceedings of the National Academy of Sciences, 104, 1266–1271. https://doi.org/10.1073/pnas.0603422104

Pankhurst, N. W., & King, H. R. (2010). Temperature and salmonid reproduction: Implications for aquaculture. Journal of Fish Biology, 76, 69–85. https://doi.org/10.1111/j.1095-8649.2009.02484.x

Pankhurst, N. W., & Munday, P. L. (2011). Effects of climate change on fish reproduction and early life history stages. Marine and Freshwater Research, 62, 1015–1026. https://doi.org/10.1071/MF10269

Pauly, D., & Pullin, R. S. V. (1988). Hatching time in spherical pelagic marine eggs in response to temperature and egg size. Environmental Biology of Fishes, 22, 261–271. https://doi.org/10.1007/BF00004892

Planas, J. V., & Swanson, P. (2008). Physiological function of gonadotropins in fish. In M. J. Rocha, A. Arukwe & B. G. Kapoor (Eds.), Fish Reproduction. Science Publishers.

Rombough, P. J. (1997). The effects of temperature on embryonic and larval development. In C. M. Wood & D. G. McDonald (Eds.), Global Warming: Implications for Freshwater and Marine Fish. Cambridge University Press.

Soria, F. N., Strüssmann, C. A., & Miranda, L. A. (2008). High water temperatures impair the reproductive ability of the pejerrey fish Odontesthes bonariensis. Physiological and Biochemical Zoology, 81, 898–905.

Tyler, C. R., Santos, E. M., & Prat, F. (2000). Unscrambling the egg—Cellular, biochemical, molecular and endocrine advances in oogenesis. In Proceedings of the 6th International Symposium on the Reproductive Physiology of Fish.

Zohar, Y., Muñoz-Cueto, J. A., Elizur, A., & Kah, O. (2010). Neuroendocrinology of reproduction in teleost fish. General and Comparative Endocrinology, 165, 438–455. https://doi.org/10.1016/j.ygcen.2009.04.017

Volume: 06 Issue No: 09

BIOHERBICIDES: A SUSTAINABLE APPROACH TO WEED MANAGEMENT

Article ID: AG-VO6-I09-53

Sruthi Gandamalla, Ajmal Siddique S*, Anwesha Barman

Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore – 641 003, Tamil Nadu, India.

*Corresponding Author : Ajmal Siddique S

Abstract

Bioherbicides are emerging as an important component of sustainable weed management, offering an alternative or complementary approach to conventional synthetic herbicides. They comprise living microorganisms such as fungi and bacteria, as well as naturally derived phytotoxic compounds that suppress weeds through pathogenicity, phytotoxins, enzymes, competition and allelochemical activity. This article reviews the major sources, mechanisms of action and important bioherbicides developed for specific weed species. Their potential advantages include target specificity, biodegradability, and diversified modes of action and reduced dependence on synthetic herbicides. However, field performance can be affected by environmental conditions, slower action, formulation and shelf-life limitations, narrow host range, production challenges and regulatory requirements. In India, research remains largely at the laboratory and glasshouse stage, highlighting the need for extensive field validation and region-specific development. Future progress depends on improved formulations, microbial consortia, advanced delivery systems, precision application and integration with cultural, mechanical and chemical methods. Bioherbicides therefore offer promising tools for sustainable integrated weed management.

Key words: Bioherbicides, Sustainable agriculture, Weed management

Introduction

Weeds are plants growing where they are not wanted, but they represent a major challenge in crop production because they compete with crops for water, nutrients, sunlight and

space from the time seedlings emerge. In cereals, the early weeks after sowing are particularly sensitive and crops affected during this critical period may not fully recover even after weeds are removed. In India, weeds are considered one of the major biological constraints on crop production. A nationwide assessment based on more than 1,500 on-farm trials reported potential yield losses of 50-76 per cent in soybean and 45-71 per cent in groundnut, with economic losses of about USD 11 billion annually across ten major crops (Gharde *et al.*, 2018). More recent estimates indicate losses of 25-26 per cent during the *kharif* season and 18-25 per cent during the *rabi* season, amounting to nearly ₹92,000 crore annually. Rice, wheat, pulses, cotton, sugarcane and groundnut are among the affected crops, although weed species and severity vary with region, soil and cropping system. Weeds also increase cult000ivation costs, as rice and cotton may require two or three rounds of manual weeding. Rising wages and shortages of farm labour during peak periods make this increasingly difficult for smallholders. Herbicides can reduce labour requirements and are often less costly than repeated manual weeding, but they remain a recurring expense and cannot prevent yield losses when weeds are not controlled at the appropriate growth stage. Thus, timely, effective and affordable weed management is essential for narrowing the gap between potential and actual yields, particularly as India seeks to produce more food from a shrinking and increasingly urbanised agricultural land base.

Synthetic herbicides became widely adopted because they are fast, relatively inexpensive and effective over large areas, but decades of intensive and repeated use have created important environmental and agronomic concerns. Herbicide residues may occur in soil, irrigation water and harvested produce, with monitoring studies in India reporting some samples above maximum residue limits. Depending on their persistence and mobility, herbicides can move beyond treated fields through surface runoff, leaching into groundwater and volatilisation, potentially affecting non-target organisms such as amphibians and aquatic invertebrates. Herbicide resistance is an especially serious practical problem. *Phalaris minor* in wheat provides a well-known Indian example, with populations in Haryana and Punjab developing resistance first to isoproturon and later to ACCase- and ALS-inhibiting herbicides, making reliable control increasingly difficult. Globally, numerous resistance cases have been documented in more than 260 weed species, with resistance continuing to expand (Islam and Monjardino, 2025). This can force farmers towards more expensive tank mixtures and premix products, potentially increasing selection pressure for further resistance. Repeated herbicide use may also suppress beneficial soil

micro-organisms, reduce below-ground biodiversity and favour smaller groups of tolerant, rapidly spreading weeds. Human exposure is another concern, particularly for workers involved in herbicide handling and spraying, while prolonged exposure to some herbicide groups has been associated with various health concerns. These issues do not mean synthetic herbicides must be abandoned, but they show the growing difficulty of relying on a limited range of chemical options from agronomic, environmental and economic perspectives.

Relying on a single weed-control method, whether chemical, mechanical or biological, can encourage weed populations to adapt to that particular pressure, as demonstrated by resistance problems in wheat and rice-wheat systems. Diversifying weed-management practices is therefore an important part of sustainable crop production. Biological approaches, including bioherbicides, provide an additional option because they use living organisms or naturally derived compounds to suppress weeds rather than depending entirely on synthetic chemistry. This different form of biological pressure may help reduce the overall use of conventional herbicides and, when appropriately integrated with other methods, contribute to resistance-management strategies (Islam *et al.*, 2024). Overuse of synthetic chemicals can potentially damage the soil and the life it supports. Chemicals may turn soil brittle, reduce the decomposition rate and minimise earthworm activity. They can also reduce the amount of nutrients in the soil, like nitrogen and iron, which promote overall health. Bioherbicides fit within the broader principles of sustainable agriculture by supporting food production while seeking to protect soil biology, water quality and long-term productivity. However, they are not a magic solution or a complete replacement for synthetic herbicides across Indian cropping systems. Their effectiveness can vary with the biological agent, target weed, environmental conditions, formulation and application timing. Their most realistic role is therefore as one component of integrated weed management, used alongside cultural practices, mechanical weeding, crop competition and, where appropriate, judicious chemical control. Such diversification can reduce dependence on any single method and provide farmers with a broader set of tools for managing changing and difficult weed populations.

Bioherbicides

A bioherbicide can be defined as a biological agent that is deliberately used to suppress, injure or kill unwanted plants. The term covers a genuinely wide range of things. On one end are living microbial agents like fungi, bacteria and, more rarely, viruses that are applied to a weed

much as a plant pathogen would naturally infect it, causing disease and eventually death or severe growth suppression. On the other end are non-living, plant-derived or microbially derived compounds: essential oils, phytochemicals, phytotoxic metabolites and other allelochemicals that damage weed tissue chemically rather than through infection. This distinction between "living agent" and "chemical-but-natural compound" matters a great deal in practice. A living microbial bioherbicide, once established on a susceptible weed population, may persist, multiply and spread to some extent under favourable conditions, similar to a natural plant disease outbreak. A plant-derived phytotoxic compound, by contrast, behaves more like a conventional herbicide in the field; it degrades after application and generally needs to be reapplied each season, even though its origin and its environmental fate differ considerably from synthetic active ingredients. What unites both categories and separates them from synthetic chemistry is that the active principle originates in nature from an organism, a plant, or a metabolite that organism produces rather than being synthesised from petrochemical feedstocks in an industrial process.

Working mechanisms

Bioherbicides suppress weeds through several mechanisms, including phytotoxins, enzymes, competition, pathogenicity and allelochemicals (Fig. 1). Many weed-pathogenic fungi and bacteria produce phytotoxins that can damage cell membranes, disturb photosynthesis and respiration, or promote reactive oxygen species; these are being explored as alternatives to living microbial formulations (Singh and Pandey, 2025). Fungi such as *Alternaria*, *Colletotrichum*, *Curvularia*, *Fusarium*, *Drechslera* and *Phoma* have demonstrated phytotoxic activity. Microbial enzymes, particularly cellulases and pectinases, degrade plant cell-wall components, facilitating colonisation and tissue collapse, often working together with phytotoxins in pathogens such as *Colletotrichum* and *Fusarium*. Some microorganisms suppress weeds through competition for nutrients, space and root-zone resources, preventing seedlings from establishing successfully (*Ocán-Torres et al.*, 2024). Pathogenicity is another important mechanism, in which fungi or bacteria infect weeds and cause leaf spots, blight, wilt or rot, reducing growth and reproduction or causing plant death. Host specificity is essential to ensure that the pathogen affects the weed without harming the crop; the rust *Puccinia abrupta* var. *partheniicola*, associated with natural epidemics on *Parthenium hysterophorus* near Bengaluru, illustrates this potential in India. Allelochemicals, including phenolics, terpenoids and alkaloids, are released by plants or microbes through leaching, volatilisation and root exudation and can inhibit weed germination

and growth by disturbing hormone signalling and inducing oxidative stress (Khamare *et al.*, 2022). Thus, bioherbicides can affect weeds through multiple biological and physiological pathways rather than a single mode of action.

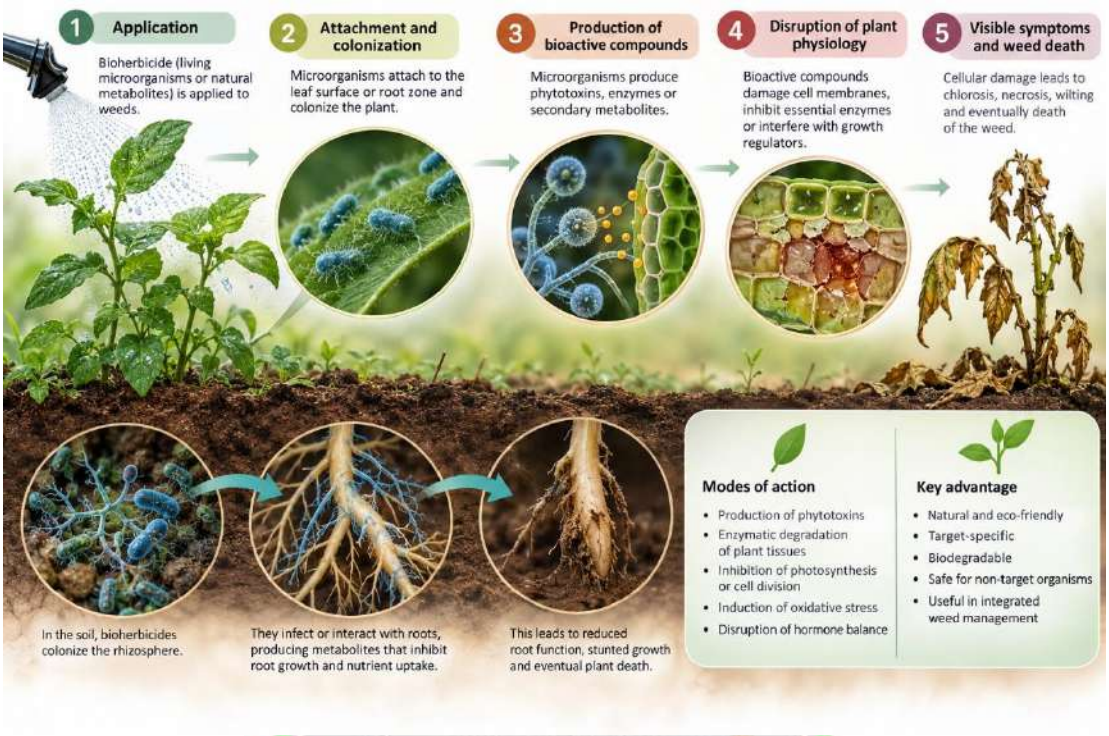


Fig. 1. Working mechanisms of bio herbicide

Major Sources

Fungi are the most extensively researched and commercially developed source of bioherbicides worldwide because many plant-pathogenic fungi are naturally host-specific, can be mass-produced as spores or mycelial fragments and follow natural infection processes such as spore germination, penetration, colonisation and disease development, which can support regulatory assessment. Important genera include *Colletotrichum, Fusarium, Alternaria, Phoma, Puccinia* and *Curvularia*. However, their effectiveness often depends strongly on suitable humidity and dew conditions for spore germination and infection. Bacterial bioherbicides are less widely developed but remain important, with *Xanthomonas* and *Pseudomonas* species and pathovars mainly acting through phytotoxic metabolites, wilting or leaf-spot diseases on susceptible weeds. Bacteria can offer practical advantages, including rapid growth during fermentation, easier genetic characterisation and, in some cases, efficient propagation, although relatively few bacterial agents have achieved sustained commercial use. Plant viruses have

received much less attention as weed-control agents, despite their major advantage of very high host specificity, which can reduce risks to crops and non-target plants. Their development is limited because viruses generally require living hosts for multiplication, are difficult to mass-produce independently and may behave unpredictably after release into field environments; therefore, virus-based bioherbicides remain largely at the research stage. Plant-derived compounds, including extracts, essential oils and other phytochemicals, represent a growing natural-product-based approach to weed management. Terpenoids and phenolic compounds in essential oils can suppress weeds by damaging cell membranes, disturbing mitosis during seed germination and inhibiting important enzymes. These compounds are closely related to allelochemicals, with the main distinction being whether they are deliberately extracted and formulated for herbicidal use or act naturally during interactions between plants. More broadly, natural products used in bioherbicide development include microbial secondary metabolites and plant compounds identified through bioprospecting and screening programmes. However, discovering a phytotoxic natural product in laboratory testing does not necessarily mean that it can become a practical field bioherbicide. Many promising compounds fail to reach commercial development because of high production costs, formulation and stability difficulties, limited field effectiveness or regulatory requirements. Thus, although fungi currently provide the strongest foundation for bioherbicide development, bacteria, viruses, plant-derived compounds and microbial natural products offer additional opportunities for developing diverse and sustainable weed-management tools.

Important Bioherbicide

Several bioherbicides have been developed and evaluated for the management of specific weed species. Important examples, their microbial agents, target weeds and trade names are presented in Table 1.

Table 1. Important bioherbicides

Pathogen	Target Weed	Trade Name
Colletotrichum gloeosporioides f. sp. aeschynomene	Aeschynomene virginica	Collego®
Colletotrichum gloeosporioides f. sp. malvae	Malva pusilla	Biomal®

Colletotrichum gloeosporioides f. sp. acutatum	Hakea sericea	Hakatak™
Phytophthora palmivora	Morrenia odorata	DeVine®
Colletotrichum gloeosporioides f. sp. cuscutae	Cuscuta spp.	LuBao
Sclerotinia minor	Taraxacum officinale	Sarritor
Chondrostereum purpureum	Prunus serotina	BioChon™
Cylindrobasidium laeve	Acacia spp.	Stumpout®
Colletotrichum coccodes	Abutilon theophrasti	Velgo®
Cercospora rodmanii	Eichhornia crassipes	ABG-5003
Alternaria cassiae	Senna obtusifolia	CASST™
Puccinia canaliculata	Senna occidentalis	Dr. BioSedge®
Puccinia thlaspeos	Crotalaria spectabilis	Woad Warrior
Xanthomonas campestris	Cyperus esculentus	Camperico®

Bioherbicides in Indian Agriculture

India's diverse cropping systems face different weed problems, creating opportunities for biological weed suppression, but also showing why bioherbicides need to be crop- and region-specific. Direct-seeded rice is particularly affected by *Echinochloa* species and sedges, while wheat in the rice–wheat belt faces resistant biotypes of *Phalaris minor*. Pulses and groundnut are highly vulnerable to early-season weed competition, with yield losses of up to 71–76 per cent reported in some trials, while cotton, maize, sugarcane, vegetables and horticultural crops have their own dominant weed floras. Among these, the invasive and allergenic *Parthenium hysterophorus* is a major concern across roadsides, wastelands and field margins, demonstrating the need for targeted biological control strategies. Indian research on biological weed management remains largely concentrated in laboratories and glasshouses, with fewer field trials and essentially no widely available commercial bioherbicide specifically developed for Indian field crops. The most sustained research effort has focused on *Parthenium* biocontrol, where

fungal pathogens such as *Fusarium, Alternaria* and *Sclerotium* isolates, together with the *Puccinia* rust, have been investigated through pathogenicity tests, greenhouse studies and observations of natural field epidemics. For rice, pulses, cotton and vegetables, research is still mainly exploratory, involving screening of native fungal isolates and evaluating allelopathic plant extracts and crop residues for weed suppression. Therefore, promising laboratory results should not be confused with registered, farmer-available products, as the transition from experimental success to reliable commercial bioherbicides remains a major challenge. The most realistic near-term role of bioherbicides in India is within integrated weed management, where they are combined with cultural, mechanical and other biological or chemical methods rather than used independently.

Cultural practices such as suitable sowing time, increased seed rate, crop rotation and weed-competitive varieties can reduce initial weed pressure, while manual and mechanical weeding remain important despite increasing labour costs. Mulching with crop residues or living covers can suppress weed emergence and conserve soil moisture, which is valuable in rainfed areas. Appropriate crop density and canopy development can further increase crop competitiveness, while rotation with competitive or potentially allelopathic crops may reduce dependence on a single weed-control method (Khamare *et al.*, 2022). However, several practical constraints may influence bioherbicide adoption, including fragmented smallholdings, difficulties in product distribution, cold-chain requirements for some living microbial formulations and limited technical support. Their effectiveness may also depend on precise humidity or dew conditions, which can be difficult to maintain under unpredictable monsoon conditions. Maintaining microbial viability during India's hot and variable storage conditions is another formulation challenge, while product cost will remain important for smallholders with limited profit margins. Thus, successful adoption will require suitable formulations, affordable products, crop- and region-specific development, realistic expectations and extensive field validation under Indian agro-climatic conditions before bioherbicides can achieve meaningful large-scale use.

Advantages

Bioherbicides offer several potential advantages for sustainable weed management. As they are derived mainly from living organisms or naturally occurring compounds, many are more readily biodegradable than synthetic herbicides and may break down faster, reducing long-term

accumulation in soil and water. However, biodegradability and environmental persistence vary between products, so their safety must be assessed individually rather than assumed from their biological origin. Many microbial bioherbicides, particularly host-specific fungal and bacterial pathogens, can have narrow host ranges, allowing them to target weeds while causing limited effects on crops and surrounding vegetation; this specificity can provide an important safety advantage, although it may also restrict their effectiveness against fields containing several weed species (Sreerama Kumar, 2024). Since bioherbicides can reduce reliance on synthetic active ingredients, their use may also lower the overall entry of chemical residues into soil, water and food, although biological agents and natural compounds still require appropriate toxicological and residue assessment (Raza *et al.*, 2025). Their greatest practical value may be within integrated weed management (IWM), where they are combined with cultural practices, mechanical control and reduced-rate herbicide use. Such diversification can reduce selection pressure from repeated use of the same herbicide and may help slow herbicide resistance development (Hou *et al.*, 2025). Bioherbicides also support the broader goals of sustainable agriculture by potentially reducing synthetic chemical dependence, supporting soil biological activity and fitting into organic or low-input systems. Nevertheless, sustainability depends on the individual product, including its production process, formulation, environmental behaviour and actual field performance, rather than simply its biological origin.

Limitations

Bioherbicides can be affected by weather conditions such as temperature, humidity, rainfall and sunlight, resulting in variable field performance. Their action may be slower than synthetic herbicides and formulation and shelf-life can be challenging. High host specificity may limit weed control. In India, mass production, field validation, farmer awareness and regulatory approval also remain important challenges.

Future Prospects

Future development of bioherbicides will focus on improving reliability, field performance and farmer adoption. Improved formulations, including protective encapsulation, controlled-release systems and better carrier materials, can enhance shelf life and protect microbial agents or natural compounds from environmental degradation (Paul *et al*., 2024). Microbial consortia may broaden weed-control activity, although strain compatibility, storage stability and regulatory requirements remain challenges (Singh and Pandey, 2025). Nanotechnology, including

nanoemulsions and nanocapsules, offers opportunities for improved delivery, but safety and environmental risks require careful assessment (La Iacona *et al.*, 2025). Integration with cultural and reduced chemical weed-management practices can further improve sustainability and help delay herbicide resistance (Hou *et al.*, 2025). Precision technologies such as AI-based weed detection and drone application may enable targeted treatment. Overall, field validation, improved formulations, regulatory development and cost-effective technologies are essential for wider adoption.

Conclusion

Bioherbicides offer a promising addition to weed management through target specificity, biodegradability and diverse modes of action. However, their effectiveness can be influenced by environmental conditions, slower action, formulation, shelf-life, narrow host range and regulatory challenges. Rather than completely replacing synthetic herbicides, bioherbicides are best integrated with cultural, mechanical and judicious chemical methods. Further field research, improved formulations, reliable production and farmer confidence are essential for wider adoption.

References

Gharde, Y., Singh, P.K., Dubey, R.P. and Gupta, P.K. 2018. Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection*, 107, 12–18.

Hou, X., Yang, Y., Liu, Q. and Zhang, B. 2025. Evolution and future directions in herbicide-resistant crop development and weed management. *Rice*, 18, Article 68. https://doi.org/10.1186/s12284-025-00869-2

Islam, A.K.M.M., Karim, S.M.R., Kheya, S.A. and Yeasmin, S. 2024. Unlocking the potential of bioherbicides for sustainable and environment friendly weed management. *Heliyon*, 10(16), e36088. (Corrigendum: *Heliyon*, 11(10), e43383, 2025.)

Islam, M.M. and Monjardino, M. 2025. The importance of developing an integrated data-driven modelling platform for herbicide resistance research: A review. *Heliyon*, 11(4), e42564. https://doi.org/10.1016/j.heliyon.2025.e42564

La Iacona, M., Scavo, A., Lombardo, S. and Mauromicale, G. 2025. The exploitation of nanotechnology in herbicides and bioherbicides: A novel approach for sustainable weed management. *Agronomy*, 15(1), 228. https://doi.org/10.3390/agronomy15010228

Maity, A., Paul, D., Govindasamy, P., Jha, R., Dutta, S. and Ali, S.A. 2026. Weed management scenario and prospects of herbicide tolerant crop technology in India. *Frontiers in Agronomy*. https://doi.org/10.3389/fagro.2026.1741164

Ocán-Torres, D., Martínez-Burgos, W.J., Manzoki, M.C., Thomaz Soccol, V., Dalmas Neto, C.J. and Soccol, C.R. 2024. Microbial bioherbicides based on cell-free phytotoxic metabolites: Analysis and perspectives on their application in weed control as an innovative sustainable solution. *Plants*, 13(14), 1996. https://doi.org/10.3390/plants13141996

Paul, S.K., Mazumder, S. and Naidu, R. 2024. Herbicidal weed management practices: History and future prospects of nanotechnology in an eco-friendly crop production system. *Heliyon*, 10(4), e26527. https://doi.org/10.1016/j.heliyon.2024.e26527

Raza, T., Qadir, M.F., Imran, S., Khatoon, Z., Khan, M.Y., Mechri, M., Asghar, W., Rehmani, M.I.A., de los Santos Villalobos, S., Mumtaz, T. and Iqbal, R. 2025. Bioherbicides: revolutionizing weed management for sustainable agriculture in the era of One-health. *Current Research in Microbial Sciences*, 8, 100394. https://doi.org/10.1016/j.crmicr.2025.100394

Singh, A.K. and Pandey, A.K. 2025. Fungal alchemy in action: Scalable, cell-free mycoherbicides for sustainable agriculture. *Journal of Plant Biota*, 4(2), 37–42.

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

Volume: 06 Issue No: 09

DESIGNING OUTCOME-ORIENTED CAPACITY DEVELOPMENT FRAMEWORKS FOR SUSTAINABLE FISHERIES AND BLUE ECONOMY GOVERNANCE

Article ID: AG-V06-I09-54

Jitendra Singh Gautam

PG Scholar, Department of Fisheries Extension, Economics, and Statistics

Fisheries College and Research institute, Thoothukudi, Tamil Nadu, India

Abstract

The blue economy, encompassing fisheries, aquaculture, marine tourism, and other ocean-based industries, offers significant opportunities for sustainable economic growth and livelihood improvement. However, achieving these benefits requires more than well-formulated policies; it demands competent human resources, adaptive institutions, and governance systems focused on measurable outcomes. This article advocates the adoption of Outcome-Oriented Capacity Development Frameworks (OCDFs) as an evidence-based approach to addressing persistent knowledge and skill gaps that hinder effective fisheries governance. Drawing upon global experiences and emerging lessons from Asia, Africa, and Latin America, the paper discusses the core components, design principles, and enabling conditions necessary for successful implementation of OCDFs in sustainable fisheries and blue economy governance.

Introduction

The world's oceans are at a crossroads. Over one-third of global fish stocks are harvested at biologically unsustainable levels, according to FAO estimates, while the blue economy — the sustainable use of ocean resources — is projected to outpace overall economic growth in many coastal nations by 2030. This tension between ecological pressure and economic opportunity is not merely a technical problem. It is, fundamentally, a governance problem.

Governments, fisheries agencies, and international bodies have invested substantially in legislation, marine protected areas, and data collection systems. Yet a critical ingredient often remains underfunded and poorly designed: the human and institutional capacity to put knowledge into practice. Fisheries officers lack training in stock assessment. Local communities

are excluded from co-management processes. Data systems exist but remain unanalysed. Policies are drafted but not implemented.

Capacity development — the process of building the skills, knowledge, and institutional systems needed for effective governance — has long been recognised as important. What has been missing is a shift from activity-based training (counting workshops and participants) to outcome-oriented approaches that ask a harder question: what changed, and did it matter?

What Is an Outcome-Oriented Capacity Development Framework?

An Outcome-Oriented Capacity Development Framework (OCDF) is a structured approach to building human and institutional competency that is explicitly anchored to governance outcomes — not training activities. Rather than measuring success by the number of workshops delivered or manuals produced, an OCDF defines what competencies need to change, by how much, within what timeframe, and with what institutional support.

At its core, an OCDF operates across three interconnected levels:

Individual Level	Building the technical and analytical skills of fisheries officers, managers, inspectors, and community leaders through targeted, role-specific learning pathways.
Organizational Level	Strengthening the systems, processes, and culture within institutions — from fisheries departments to NGOs — so that individual competencies translate into institutional performance.
Enabling Environment	Addressing the policy, legal, and financial structures that either support or obstruct effective fisheries governance, including inter-agency coordination and community participation mechanisms.

The framework is designed iteratively. It begins with a competency needs assessment — mapping the gap between current institutional performance and the demands of sustainable fisheries governance — then sequences learning interventions, embeds mentorship and peer learning, and closes each cycle with rigorous outcome evaluation. Crucially, it distinguishes between outputs (a training manual produced), outcomes (officers applying new skills in licensing decisions), and impact (measurable improvement in fish stock health).

Designing for the Blue Economy: Key Principles

Applying an OCDF to blue economy governance introduces unique design considerations. Unlike terrestrial resource management, ocean governance is inherently transboundary, multi-

sectoral, and ecologically complex. The following five principles have emerged from frameworks deployed across Pacific island nations, West African fisheries cooperatives, and South Asian aquaculture regions.

1. Context-First Design

No single capacity development model fits all contexts. Frameworks must begin with a deep situational analysis — examining existing legal mandates, informal governance structures, cultural relationships with the sea, and the political economy of fisheries. A Pacific small island state managing tuna stocks faces entirely different challenges than an Indian coastal district managing near-shore artisanal fisheries

2. Competency Mapping Tied to Governance Roles

Effective OCDFs map required competencies directly to governance functions. Stock assessment officers need different skills than community liaison officers or maritime patrol personnel. Role-specific learning pathways prevent the generic 'one workshop for all' approach that historically produces little lasting change.

3. Multi-Actor Engagement

Blue economy governance is a multi-stakeholder endeavour. Capacity frameworks must include not only government officials but also fishing communities, women fish traders, private sector actors, and civil society. Frameworks that bypass community knowledge systematically underperform — traditional ecological knowledge can be critical data for stock assessments.

4. Adaptive Management Loops

Frameworks must build in regular reflection and adaptation cycles. Monitoring and evaluation are not end-of-project activities; they are continuous processes that allow frameworks to respond to new ecological data, policy changes, or unexpected governance challenges.

5. South-South Learning and Knowledge Exchange

Some of the most valuable capacity development happens not through expert-to-novice transfers from the Global North, but through peer learning among countries facing similar challenges. Regional networks — such as the SWIOFISH programme in the Western Indian Ocean — have demonstrated that horizontal knowledge exchange builds ownership and durability

Measuring What Matters: The Outcomes That Count

Perhaps the greatest challenge in outcome-oriented frameworks is defining outcomes that are both measurable and meaningful. Fisheries governance outcomes exist on a spectrum —

from immediate behavioural changes (an officer correctly applying a gear restriction regulation) to long-term ecosystem outcomes (a recovering coral reef or a commercially viable fish population). OCDFs must work across this spectrum without losing rigour.

A practical outcome measurement approach for fisheries capacity development might include three tiers:

TIER	OUTCOME DOMAIN	EXAMPLE INDICATORS
Tier 1 (Short-term)	Knowledge & Skill Application	% of officers demonstrating correct stock assessment procedures; pre/post knowledge tests scores
Tier 2 (Medium-term)	Institutional Performance	Timeliness of fisheries reporting; increase in co-management agreements signed; compliance rates
Tier 3 (Long-term)	Governance & Ecological Impact	Trends in fish stock biomass; livelihoods of fishing communities; MPA effectiveness scores

Attribution remains a genuine challenge: multiple factors — climate variability, illegal fishing, market shifts — affect fish stocks simultaneously. OCDFs address this through contribution analysis rather than strict attribution, asking 'how much did our capacity investments contribute to observed outcomes?' rather than claiming sole causality. This is not methodological weakness — it is scientific honesty.

Pathways Forward: From Framework to Practice

The evidence is clear: investments in capacity development yield better fisheries governance outcomes when they are systematically designed around results, contextually grounded, and sustained over time. A one-off workshop cannot transform an institution. A well-designed OCDF — embedded in national fisheries strategy, adequately resourced, and politically championed — can.

Several priority actions will accelerate the adoption of outcome-oriented frameworks across blue economy governance systems. National fisheries agencies and blue economy ministries should commission competency audits that map current capacity against governance

demands — not what training was delivered, but what skills are actually being applied. Donors and development partners must shift funding modalities from project-cycle training to sustained programme support that allows adaptive learning over five-to-ten-year periods. Regional fisheries bodies — SEAFDEC, SWIOFISH, OSPESCA, and others — are well placed to establish shared competency standards and facilitate peer learning exchanges. Universities and technical institutions must integrate fisheries governance, blue economy law, and ocean data science into curricula that feed qualified professionals directly into the governance pipeline. Finally, monitoring and evaluation systems must be treated as core infrastructure — not optional add-ons — with dedicated resources and independent oversight.

The blue economy will not govern itself sustainably by virtue of good intentions. It requires people — trained, empowered, and supported by functional institutions — making evidence-based decisions at every level, from the village fishing committee to the inter-ministerial policy table. Outcome-oriented capacity development frameworks are not a silver bullet. But they are among the most powerful, underutilised tools we have for building the governance capacity our oceans urgently need.

Conclusion

The sustainability of fisheries and the success of the blue economy depend not only on sound policies and advanced technologies but also on the capacity of individuals and institutions to implement them effectively. Traditional training approaches often fail because they emphasize activities rather than measurable results. Outcome-Oriented Capacity Development Frameworks provide a practical solution by linking skill enhancement with institutional performance and governance outcomes.

By promoting evidence-based decision-making, inclusive participation, continuous learning, and adaptive management, OCDFs help bridge the gap between knowledge and action. Strengthening human and institutional capacities will ultimately enhance fisheries governance and contribute to resilient coastal communities, sustainable fish stocks, and a thriving blue economy.

References

Food and Agriculture Organization. (2022). *The state of world fisheries and aquaculture 2022*. Rome: FAO.

Béné, C., Barange, M., Subasinghe, R., Pinstrup-Andersen, P., Merino, G., Hemre, G. I., & Williams, M. (2015). Feeding 9 billion by 2050—Putting fish back on the menu. *Food Security, 7*(2), 261–274.

Organisation for Economic Co-operation and Development. (2016). *The ocean economy in 2030*. Paris: OECD Publishing.

Pita, C., Pierce, G. J., & Theodossiou, I. (2014). Stakeholder participation in fisheries management: Lessons from practice. *Marine Policy*, *44*, 83–91.

Jentoft, S., & Chuenpagdee, R. (2023). *Interactive governance for small-scale fisheries: Global reflections*. Springer.

World Bank. (2017). *The potential of the blue economy: Increasing long-term benefits of the sustainable use of marine resources for small island developing states and coastal least developed countries*. Washington, DC: World Bank Group.

Volume: 06 Issue No: 09

EVERY DROP COUNTS: SMART WATER MANAGEMENT FOR MODERN AGRICULTURE

Article ID: AG-V06-I09-55

S. Pranava Mari Muthu[1] and R. Raja Priya[2]

[1]M.Sc. (Agriculture) First Year Student, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.

[2]Assistant Professor, Department of Agronomy, Roever Agricultural College, Perambalur, Tamil Nadu, India.

*Corresponding Author : S. Pranava Mari Muthu

Introduction

Water is the foundation of agricultural production and one of the most valuable natural resources for sustaining food production. Agriculture accounts for a major share of freshwater use in many regions, making efficient water management essential for achieving food security and environmental sustainability. Rapid population growth, irregular rainfall, declining groundwater levels, frequent droughts and increasing temperatures are placing unprecedented pressure on agricultural water resources. Under these circumstances, the challenge before modern agriculture is not simply to produce more food, but to produce more with less water while protecting soil health and farm profitability.

Efficient water management involves much more than reducing irrigation. It means **applying the right quantity of water, at the right time, in the right place and through the most appropriate method**. By combining improved irrigation practices, soil and crop management, rainwater harvesting and modern digital technologies, farmers can increase water-use efficiency while maintaining crop productivity.

Understanding Crop Water Requirements

Water is essential throughout the crop growth cycle, from seed germination and vegetative development to flowering, fruit formation and maturity. However, the amount of water required differs among crops and depends on soil type, climate, crop growth stage and prevailing weather conditions.

Excessive irrigation does not necessarily result in higher yields. Over-irrigation can create waterlogging, reduce soil aeration, promote nutrient leaching and increase the incidence of certain pests and diseases. In contrast, inadequate water supply can cause water stress, reducing photosynthesis, plant growth and ultimately crop yield.

Drip Irrigation: Supplying Water Directly to the Root Zone

Drip irrigation is an important water-saving technology in modern agriculture. In this system, water is delivered slowly and precisely to the soil near the plant root zone through emitters. This targeted application reduces unnecessary wetting of the soil surface and minimizes water losses through evaporation and runoff.

Drip irrigation is especially useful for vegetables, fruit crops, sugarcane, cotton and other crops grown with wider plant spacing. The system can also be combined with **fertigation**, in which nutrients are supplied along with irrigation water. This allows both water and nutrients to be delivered closer to the active root zone, improving resource-use efficiency.

Sprinkler Irrigation: Efficient and Uniform Water Application

Sprinkler irrigation applies water to the field as small droplets, resembling natural rainfall. It is particularly useful in situations where land is uneven or where uniform water distribution is required.This method can be effectively used for crops such as groundnut, pulses, vegetables, fodder crops and several other field crops. However, appropriate sprinkler selection and proper system operation are essential. Strong winds and high temperatures can increase evaporation losses, reducing irrigation efficiency.

Managing Soil Moisture for Better Water Use

Effective water management begins with proper understanding of the soil. Different soils have different capacities to store and supply water to plants. Sandy soils generally hold less water and may require smaller but more frequent irrigation, whereas clay soils can retain greater quantities of water but may experience poor drainage when excessive irrigation is applied.

Several soil management practices can improve water conservation. **Mulching, conservation tillage, crop-residue retention and the addition of organic matter** can enhance soil structure and improve its ability to retain available moisture.

Organic mulches such as crop residues and straw can reduce direct evaporation from the soil surface. They also help moderate soil temperature and suppress weeds, thereby reducing competition between weeds and crops for available water.

Precision Irrigation: Bringing Technology to the Field

Digital agriculture is transforming the way irrigation decisions are made. Technologies such as **soil-moisture sensors, automated weather stations, satellite imagery, drones and mobile-based applications** can provide valuable information about crop and field conditions.

Soil-moisture sensors can help determine whether sufficient moisture is available in the root zone and indicate when irrigation is required. This enables farmers to make irrigation decisions based on actual field conditions rather than relying entirely on visual assessment.

Similarly, remote sensing and satellite-based technologies can identify differences in crop growth and water stress across a field. Such information creates opportunities for more targeted irrigation and better utilization of available water resources.

Rainwater Harvesting: Saving Water for Dry Periods

Rainwater is an important source of agricultural water, particularly in rainfed and water-limited regions. Instead of allowing valuable rainfall to leave the farm as surface runoff, farmers can adopt suitable rainwater-harvesting measures such as **farm ponds, check dams, contour bunds and percolation ponds**.

Stored rainwater can be used as supplementary irrigation during dry periods. At the same time, structures designed for groundwater recharge can improve infiltration and contribute to more sustainable water availability over the long term.

Conservation Agriculture for Water Conservation

Water management and soil management are closely interconnected. Conservation agriculture practices such as **minimum soil disturbance, crop-residue retention and crop diversification** can improve soil structure and water infiltration.

A healthy soil provides a favourable environment for root development and can improve the storage and supply of water to crops. Increasing soil organic matter is particularly beneficial because it contributes to better soil aggregation and improves water-holding capacity.

Choosing the Right Crop for Available Water

A fundamental principle of water-smart farming is **"Right Crop, Right Place."** Crop selection should consider local rainfall, groundwater availability, soil characteristics and the availability of irrigation facilities.

In areas where water is limited, farmers may consider drought-tolerant and relatively water-efficient crops such as **millets, pulses and suitable oilseeds**, provided they are compatible

with local agro-climatic and economic conditions. Selecting crops according to available water resources can reduce irrigation pressure while supporting sustainable farm production.

Smart Irrigation Scheduling

Efficient irrigation depends not only on the quantity of water applied but also on **when the water is applied**. Irrigation during periods of intense heat and strong sunlight can increase evaporation losses. Wherever practical, irrigation should therefore be scheduled during periods of lower evaporative demand.

When water availability is limited, irrigation should be prioritized during crop growth stages that are particularly sensitive to water stress. Flowering, pollination and early stages of fruit or seed development are critical periods for many crops.

Minimizing Water Losses in the Field

A significant amount of irrigation water may be lost before it reaches the crop root zone. Leakage from irrigation channels and pipelines, excessive runoff and poorly maintained irrigation equipment can reduce overall water-use efficiency.

Several simple management practices can help minimize these losses:

- Regularly repair leaking pipes and irrigation channels.
- Maintain irrigation equipment properly.
- Level fields wherever appropriate.
- Minimize unnecessary surface runoff.
- Select irrigation methods suitable for the crop and soil.
- Control weeds that compete for soil moisture.
- Apply suitable mulch materials.
- Avoid unnecessary or excessive irrigation.

Integrating Nutrient and Water Management

Water and nutrient management should not be considered separately. Excessive irrigation can move soluble nutrients below the active root zone, reducing nutrient-use efficiency and potentially contributing to groundwater contamination.

Balanced fertilization and fertigation can help synchronize the supply of water and nutrients with crop demand. Applying appropriate quantities of nutrients at suitable growth stages can help crops utilize available water more effectively.

Empowering Farmers for Better Water Management

Technology is an important component of efficient water management, but successful water conservation ultimately depends on farmers and their management decisions. Local knowledge, awareness, technical guidance and proper operation of irrigation systems are equally important.

Water-saving technologies should be selected according to **farm size, crop type, soil characteristics, water availability, investment capacity and local climatic conditions**. Farmer training, field demonstrations and extension support can encourage the effective adoption and operation of efficient irrigation technologies.

Towards a Water-Smart Agricultural Future

The future of agriculture depends not only on increasing food production but also on using natural resources responsibly. Efficient water management provides an opportunity to sustain crop productivity while reducing pressure on groundwater and surface-water resources.

The objective should not be simply **"more irrigation," but "more crop per drop."** Integrating drip or sprinkler irrigation with soil-moisture monitoring, rainwater harvesting, mulching, conservation agriculture, appropriate crop selection and precision technologies can contribute to more resilient and sustainable farming systems.

Save water today, secure food tomorrow. In modern agriculture, every drop counts.

References

Food and Agriculture Organization of the United Nations. (n.d.). *Agricultural water management*. FAO.

Food and Agriculture Organization of the United Nations. (n.d.). *Irrigation management*. FAO.

Food and Agriculture Organization of the United Nations. (n.d.). *Water scarcity*. FAO.

Jain, R., Kishore, P., & Singh, D. K. (2019). Irrigation in India: Status, challenges and options. *Journal of Soil and Water Conservation, 18*(4).

Kishore, P., Chand, S., & Srivastava, S. K. (2022). Potential area of micro-irrigation and its outreach across Indian states. *Indian Journal of Agricultural Sciences, 92*(9), 1056–1060. https://doi.org/10.56093/ijas.v92i9.101138

Reddy, K. S., Nayak, S., Mandi, S., Baral, K., & Shivay, Y. S. (2023). Micro-irrigation: Way forward for precise use of irrigation water in agriculture. *Indian Farming, 73*(2), 18–20.

Gurjar, D. S., Khodke, U. M., & Kaur, R. (2018). Micro-irrigation in India—Present status and future prospects. *Indian Farming*, *67*(7).

Indian Council of Agricultural Research. (2019, September 5). *Water conservation & "More Crop Per Drop" is possible through micro irrigation*. ICAR.

Indian Council of Agricultural Research. (n.d.). *Indian Institute of Water Management*. ICAR.

NITI Aayog. (2019). *Efficiency of micro-irrigation in economising water use in India: Learning from potential and under explored states*. Government of India.

Volume: 06 Issue No: 09

INFECTIOUS CORYZA IN POULTRY: A MAJOR RESPIRATORY CHALLENGE FOR FARMERS

Article ID: AG-V06-I09-56

Dr.M. Lakshmi Namratha

Assistant Professor, Department of Veterinary Pathology, College of Veterinary Science, Mamnoor, Warangal, India

Abstract

Infectious coryza is an important respiratory disease of poultry affecting the upper respiratory tract caused by *Avibacterium paragallinarum*. The disease spread rapidly through the flock, causing considerable production losses, particularly in commercial layer and breeder birds. Common clinical signs include facial and infraorbital swelling, nasal and ocular discharges, conjunctivitis, reduced feed intake, and a noticeable decline in egg production. Diagnosis is based on clinical and flock history, bacterial isolation, and molecular techniques such as PCR. Antimicrobial treatment may help reduce clinical disease and production losses, but treatment alone is often insufficient to prevent recurrence. Effective control therefore requires a combination of early diagnosis, appropriate veterinary treatment, vaccination where indicated, strict biosecurity, good sanitation, adequate ventilation, stress reduction, and appropriate flock management. A better understanding of the disease and its risk factors can help farmers recognize outbreaks early and implement effective measures to protect flock health, productivity, and farm profitability.

Keywords: *Avibacterium paragallinarum*, infectious coryza, facial edema, biosecurity and vaccination.

Introduction

Infectious coryza is an acute and highly contagious bacterial disease of chickens caused by Avibacterium paragallinarum, primarily targets the upper respiratory tract (Blackall *et al.*, 2005). Infected birds typically develop signs such as rhinitis, sinusitis, nasal discharges, facial edema and respiratory distress. In commercial layer and breeder flocks, infectious coryza can

lead to a substantial reduction in egg production and adversely affect overall flock performance. The disease spreads rapidly, with morbidity rates reaching 60–80% and mortality is usually low, ranging from 1–15%. Mortality rates are high when the infection is complicated by other pathogens. Recovered birds continue to shed the organism and remain carriers, serving as an important source of infection and contributing to the spread of the disease among susceptible birds.

Transmission

Chickens of different ages are susceptible, but the severity of the disease varies depending on the bird's age, immunity, housing conditions, stress and other infections. The disease spreads mainly when healthy birds come into direct contact with infected or carrier birds. It can also spread through contaminated drinking water, feeders, equipment, cages, clothing, footwear and the hands of farm workers. One of the biggest challenges in controlling coryza is the presence of carrier birds. Recovered birds appear healthy but may continue to shed the bacteria. Farmers should follow an appropriate quarantine period before introducing the new flock into the main flock.

Pathogenesis

Following entry, the bacteria colonizes in the mucosal surfaces of the upper respiratory tract and adheres to respiratory epithelial cells. The bacteria multiply locally and produce an inflammatory response resulting in the inflammation of the nasal mucosa and infraorbital sinuses. There is accumulation of inflammatory exudates within the sinuses that contributes to facial and infraorbital swelling.

The severity of disease is influenced by secondary infections and predisposing factors. Concurrent infections with respiratory pathogens, poor ventilation, high stocking density, environmental stress and inadequate management can exacerbate the disease. Thus, infectious coryza should not always be considered an isolated bacterial infection; it may form part of a broader multifactorial respiratory disease complex.

Clinical Manifestations

The severity of the disease can differ between flocks. It depends on the strain of bacteria, the bird's immunity, and presence of concurrent infections. One of the most noticeable signs is facial edema, especially around the eyes and infraorbital sinuses. Birds may develop a watery

nasal discharge that gradually becomes thick and mucus-like. Discharge may also be seen around the eyes, and the eyes can become red and inflamed.

In severe cases, birds may develop **thick, purulent discharge from the nares and eyes**, often accompanied by a **characteristic fetid odor**. Respiratory distress, reduced feed intake, weakness, and subsequent loss of body weight may also occur.

In laying hens, infectious coryza can cause a drop in egg production and egg quality, resulting in significant economic losses for farmers (Deshmukh *et al.*, 2015). The infection can also spread deeper into the respiratory tract, affecting the trachea and air sacs and, in very severe cases, causing pneumonia.

Mortality rates are high when the disease is complicated by other infections, such as Mycoplasma gallisepticum (Beach and Schalm, 1936).



Chicken showing facial edema, swollen infraorbital sinuses and open mouth breathing

Diagnosis

Diagnosis is made based on the clinical signs, flock history, post-mortem findings, and laboratory testing. Bacterial isolation and molecular tests such as PCR can be used to confirm the presence of *A. paragallinarum*.

Laboratory confirmation is particularly useful when the disease is severe, several respiratory diseases are possible, repeated outbreaks, treatment does not produce the expected response and vaccination or long-term control programme is being considered

Treatment

Treatment of infectious coryza should be undertaken under veterinary supervision.

Antimicrobial therapy can help reduce clinical signs, bacterial load, and disease-associated production losses. The selection of an appropriate antimicrobial should be based on clinical assessment, disease history, and, where feasible, antimicrobial susceptibility testing. In addition, appropriate biosecurity and flock-management measures are essential to minimize recurrence and transmission within the flock. Treatment alone may not prevent the disease from returning if infected or carrier birds remain in the flock and biosecurity problems are not corrected.

Prevention and control

Prevention is an important part of managing infectious coryza. Good biosecurity can reduce the chance of introducing the infection and can limit its spread within the farm.

- **Maintain strict biosecurity:** Restrict unnecessary movement of personnel, equipment, and birds between poultry houses. The use of dedicated protective clothing and footwear within individual poultry units can reduce the mechanical transmission of infectious agents between flocks.
- **Avoid mixing birds:** Avoid mixing birds of different ages and minimize the introduction of new birds into established flocks without appropriate health screening and biosecurity measures. All-in/all-out flock management can help reduce the persistence and transmission of infectious coryza within the farm.
- **Maintain effective sanitation and hygiene:** Poultry houses, feeders, drinkers, and other equipment should be routinely cleaned and disinfected. Manure, litter, and other organic matter should be removed thoroughly before disinfection, as the presence of organic material can reduce the effectiveness of many disinfectants.
- **Ensure adequate ventilation:** Proper ventilation is essential for maintaining air quality and respiratory health. Inadequate ventilation can result in the accumulation of dust, moisture, and ammonia, which may impair respiratory mucosal defenses and increase susceptibility to respiratory infections.
- **Minimize stressors:** Management-related stressors, including overcrowding, inadequate nutrition, abrupt environmental changes, transportation, and inappropriate housing conditions, may increase disease susceptibility and exacerbate clinical manifestations. Maintaining appropriate stocking density, balanced nutrition, environmental temperature, ventilation, and overall flock management is essential for maintaining optimal health and immunity.

- **Vaccination:** Vaccination is important in prevention and control of infectious coryza, particularly in farms with a history of recurrent outbreaks. The vaccination programme should be developed in consultation with a poultry veterinarian, taking into consideration the epidemiological situation, prevalent *Avibacterium paragallinarum* strains, and the farm's disease history.

Conclusion

Infectious coryza can spread rapidly reducing production even though the mortality is low. Facial swelling, nasal and eye discharge, conjunctivitis, respiratory difficulty, reduced feed intake, and decreased egg production are important warning signs. Early recognition, veterinary diagnosis, appropriate treatment, vaccination where indicated, and strong biosecurity are the main tools for controlling infectious coryza and protecting flock productivity.

References

Blackall, P. J., Christensen, H., Beckenham, T., Blackall, L. L., & Bisgaard, M. (2005). Reclassification of Pasteurella gallinarum,[Haemophilus] paragallinarum, Pasteurella avium and Pasteurella volantium as Avibacterium gallinarum gen. nov., comb. nov., Avibacterium paragallinarum comb. nov., Avibacterium avium comb. nov. and Avibacterium volantium comb. nov. *International Journal of Systematic and Evolutionary Microbiology*, *55*(1), 353-362.

Beach, J. R., & Schalm, O. W. (1936). Studies of the clinical manifestations and transmissibility of infectious coryza of chickens. *Poultry Science*, *15*(6), 466-472.

Deshmukh, S., Banga, H. S., Sodhi, S., & Brar, R. S. (2015). An update on avian infectious coryza: It's re-emerging trends on epidemiology, etiologic characterization, diagnostics, therapeutic and prophylactic advancements. *J. Dairy Vet. Anim. Res*, *2*(3), 86-92.

Volume: 06 Issue No: 09

IMPORTANCE OF PRO-TRAY NURSERY IN VEGETABLE CULTIVATION

Article ID: AG-VO6-I09-57

Dr. S.Senthilkumar

Senior Scientist and Head, ICAR- Krishi Vigyan Kendra,

Gandhigram Rural Institute (Deemed to be University), Gandhigram, Dindigul -624302, India

Introduction

India's diverse climate ensures availability of all varieties of vegetables. It ranks second in vegetables production in the world, after China. Healthy seeds and seedlings are the first and most important elements for every vegetable crop to reach its maximum yield potential. Superior quality seedlings are well known to be the necessary prerequisite for high quality vegetable production. An old Japanese quote says that the seedling determines half of the crop yield, which clearly reflects the most sensitive phase of the plant growth influencing its future performance and the need to take utmost care to provide optimum conditions to produce high quality seedlings. Since the hybrid seeds are expensive, the pro-tray nursery method helps to reduce cost by minimizing the seed wastage. There has been a shift from growing transplants on flat and raised nursery beds in the open field towards growing designed containers such as Seedling trays (or) Plug trays (or) Protrays.

Protray nursery technology is a modern method for growing healthy, uniform vegetable seedlings in individual cells using a controlled, sterile medium. The pro-tray nursery seedlings free from pest and diseases and develop good root system within 25-30 days (Bryant, 1995)

Key Materials and Preparation

Seedling Production in Trays

Vegetable nurseries generally grow the seedlings of F1 hybrid vegetables, which are gradually replacing the open pollinated varieties. Since, the hybrid seeds are expensive; the tray grown vegetable seedlings are becoming popular as this method of raising the seedlings minimizes the loss of seeds and seedlings.

Protected structures

A seedling needs as much care and nourishment as a child. A protected and congenial enclosure is necessary to grow healthy seedlings. Vegetable seedlings are being grown in low cost poly houses and net houses. The mainframe can be of steel pipes, wooden poles or granite stone pillars.

Net house

In recent years net houses are becoming popular to raise vegetable seedlings. Granite pillars of 6 to 8 feet long are erected as the mainframe of the net house. The roof is generally covered with a shade net and the sides are covered with an insect proof net. However, it is advisable to cover the roof also with an insect proof net to have better control over the entry of insect vectors like white flies which may be carried by the air currents gain entry into the net house. A shade net will be useful to regulate the shade in the green house depending on the light level prevailing in the green house. Plastic pipes of ¾ inch are bent in arch shape over the nursery beds and are covered with a plastic sheet to protect the seedlings from rain during rainy days. This structure provides adequate light, shade and humidity and also protects the seedlings from thrips, white flies and aphids that spread the viral diseases.

Seedling trays

The seedling trays are known as pro trays, flat trays and plug trays. These trays made of polypropylene can be reused up to 6 times to grow seedlings. Before using every time it is necessary that these trays are thoroughly washed and disinfected with a fungicide. The holes at the bottom of the cells control the moisture properly. Equi-spaced cells facilitate even growth of the seedlings. Protrays with 98 cells are commonly used to raise the seedlings of tomato, capsicum, cabbage, cauliflower, chilli and brinjal. The size of the tray is generally 54 cm long and 27 cm wide.

Growing media for seedling trays

Sterilized commercial growing media is better as the incidence of seedling diseases is less or nil and contains right amount of moisture in it. The most common growing media used is coco peat, a by-product of coir industry and it has high water holding capacity. It should be well decomposed, sterilized and supplemented with major nutrient sources before using. Basically coconut fibre powder is low in nutrients and high in lignin content. Thus it needs to be properly decomposd by adding major and micronutrients and microorganisms.

Method of seedling raising

- Fill the seedling tray with the appropriate growing medium.
- Coco peat (Coir dust) is the popular medium being used by many farmers.
- About 100 kg coco peat are required to fill 100 trays.
- Make a small depression (0.5 cm) with fingertip, in the center of the cell sowing. Alternatively, depression can be created by stacking about 10 trays one over other and pressing the trays together.
- Sow one seed per cell and cover by medium
- No irrigation is required before or after sowing if coco peat bagged is used.
- Keep about 10 trays one over the other for 3 to 6 days, depending on the crops. Cover the entire stack of tray with polyethylene sheet. This arrangement ensures the conservation of moisture in the seedling trays until germination and hence no irrigation is required till seedling emergence. Care must be taken for spreading the trays when the seedling is just emerging.
- Seeds start emerging after about 3-6 days of sowing depending upon the crops. Then the trays are kept spread over a bed covered with polyethylene sheet.
- The germinating trays are then irrigated lightly, daily depending upon the prevailing weather conditions. Never over irrigate the trays, as it results in the leaching of nutrients and help in building up of diseases.
- The trays are also drenched with funcigides as a precautionary against seedling mortality.
- Seedling trays are watered daily, using a fine sprinkling water can with hose pipe fitted to rose.
- The media may need supplementation of nutrients show deficiency symptoms. Spray 0.3 per cent (3g/lit) of 100 percent water soluble fertilizer (19:19:19) twice (12 and 20 days after sowing).
- Protect the trays from rain by covering with polyethylene sheets in the form of low tunnel.
- Harden the seedlings by withholding irrigation and reducing the shade before transplanting.
- The seedlings will be ready in about 21-42 days for transplanting into the main field depending upon the crop.

Table: 1 Nursery duration for various vegetables

S.No	Crops	Nursery duration (Days)
1	Tomato	25-28
2	Chillies	35-40
3	Capsicum	35-40
4	Brinjal	35-40
5	Cabbage	25-30
6	Cauliflower	25-30
7	Watermelon	12-15



Pro-trays





Fill the seedling tray with cocopeat and sow the seeds.



Stack about 10 filled trays





Uniform growth and healthy seedlings

Advantages of growing vegetable seedlings in plastic trays

- Seeds germinate properly
- Mortality of seedlings is very rare, which is common in open field nurseries
- Minimum wastage of expensive seeds
- There is adequate space for each seedling to grow properly
- Equal and healthy growth of each seedling
- Damage due to pests and diseases is very rare
- Sterilized media prevents damping –off and root rot diseases.

- Seedlings do not wither during transport
- Better root growth
- Damage to roots is very rare during shifting to planting
- Ease in handling
- Uniform and early maturity

Conclusion

Vegetable seedling production has become a widely commercialised sector, with the majority of farmers adopting this technology and purchasing seedlings from government institutions or professional producers and protray raising getting popularised now a days due to the uniform growth of plants, better root growth and free from pest and diseases. It is clear from the fore going that raising vegetable seedlings in seedling trays is the best option to produce healthy seedlings that gives quick start to the crops grown in open and greenhouses.

References

Bryant,G.1995. Propagation Handbook. Stackpole Books: Mechanicsburg, Pennsylvanis.

Kulveer Sing Yadav and Anurag Bajpay.2019. Nursery pro-trays and its importance in horticulture. *An International Journal of Floriculture Science and Landscaping – The Journal of the Greens and Gardens*, 01(02): 27-28

Production Technology of Vegetables- A Hand Book.2010. Indian Institute of Horticultural Research, Hessaraghatta Lake Post, Bangalore.

Quality Vegetable Seedling Production.2004. Indian Institute of Horticultural Research, Hessaraghatta Lake Post, Bangalore.

Vadivel.E., and I.Muthuvel. Thulliya Pannai tholilnutpankal (Tamil). Sri Devi Litho Graphics, Robertson road, Coimbatore.

Volume: 06 Issue No: 09

THE POWER OF POLLINATORS

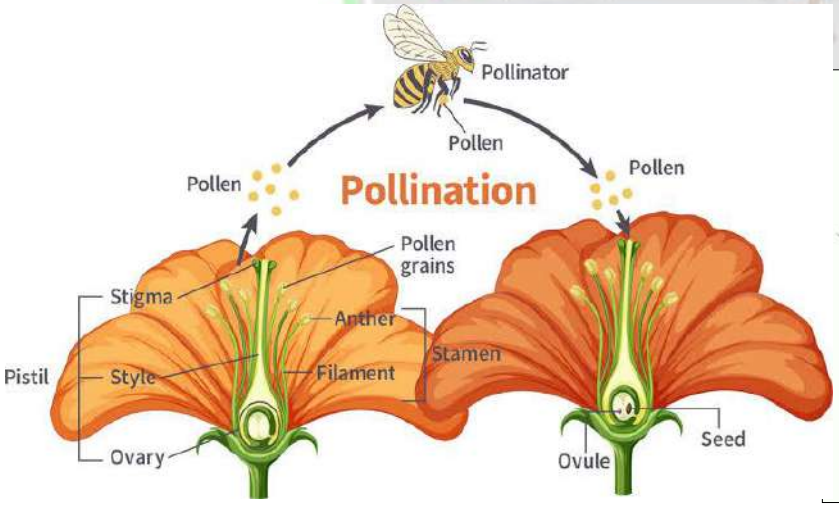
Article ID: AG-V06-I09-58

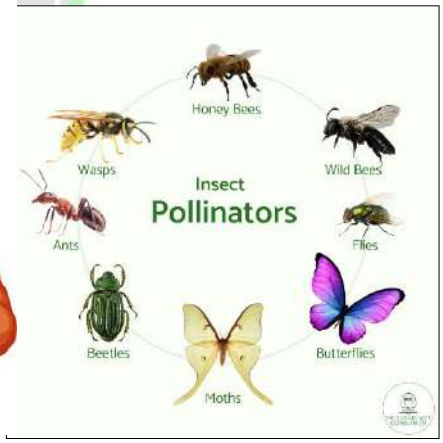
Balaji M

B.Sc. (Hons.) Horticulture, Horticultural College & Research Institute (TNAU), Periyakulam, Theni, Tamil Nadu - 625 604, India

Introduction

Pollination in plants is the process of transferring pollen grains from the male part of a flower (the anther) to the female part (the stigma). This transfer is essential for fertilisation, allowing male gametes to fertilise the ovules inside the ovary, leading to the production of seeds and fruit. Pollination is vital for the survival of wild plants and most fruit and seed crops, supporting ecosystem stability and global food production.





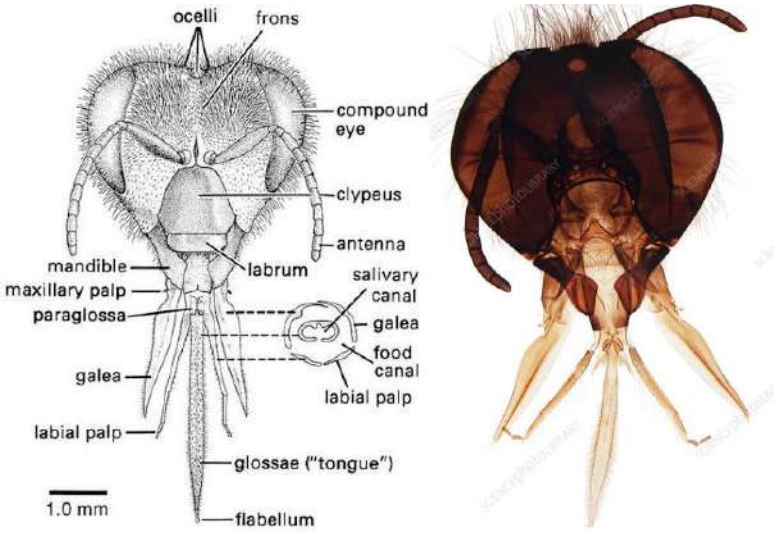
Pollinators

Pollination can occur through various agents, including wind, water and animals, especially insects and is crucial for the reproduction of many flowering plants. Those pollinating agents are termed “Pollinators”. Pollination relies on various animals and insects to transfer pollen between plants, ensuring the continuation of ecosystems and the production of many crops. Among these, bees stand out as crucial pollinators, playing an important role in the

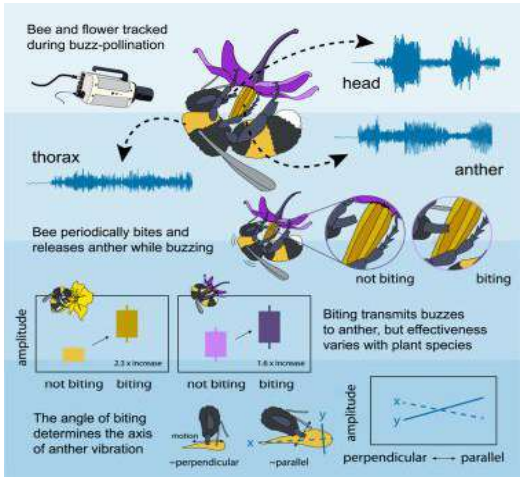
reproduction of numerous plant species and the formation of fruits and seeds. Bees are the most important insect pollinators, with over 20,000 species that feed on nectar and pollen. They have physical and behavioural adaptations such as hairy bodies and long tongues to aid in pollination. Other insect pollinators include beetles, flies, birds and rats. Some flowers attract carrion beetles and flesh flies with a smell of rotting flesh. Some insects are attracted to the yellow colour of the flowers, mostly cucurbits.

Bees – Nature's Master Gardeners

In the modern world, bees are probably the most important insect pollinators. Living almost exclusively on nectar, as adults, they feed their larvae with pollen, nectar and royal jelly. To obtain their food, they possess striking physical and behavioural adaptations, such as **chewing- and lapping- type** mouthparts with tongues as long as 2.5cm (1 inch), often hairy bodies (foragial legs) and special pollen baskets. Bees collect pollen by the **Buzz pollination** technique, in which bees decouple their flight muscles from their wings and vibrate their thorax, producing a high-pitched buzz. Bees grasp the flower with their legs and often use their mandibles to bite onto the anther cone for a firm grip, transmitting vibrations directly to the flower. The speed and intensity of these vibrations influence the amount of pollen released. The resulting pollen falls onto the bee's body and is collected in the hairy body parts of the bee, which act as a pollen basket. Bees are exceptionally efficient pollinators compared to other species because their fuzzy bodies act as natural "**pollen magnets**", and they have specialised **grooming** behaviours to pick up, carry, and transfer pollen between flowers. Other insects like flies and butterflies just visit flowers and suck the nectar.



Chewing and lapping type of mouthpart – Honeybee



Action of Buzz Pollination by Bees

Effect of Bee pollination on crops

- Bee pollination improves the quality of fruits and seeds.
- Bee pollination increases yield in terms of seed yield and fruit yield in many crops.
- Bee pollination is a must in some self-incompatible crops for seed set.
- Bee pollination increases the oil content of seeds in sunflower.

The total area of bee-dependent crops in India is around 50 million hectares. One hundred and fifty million colonies are needed to meet this, at the rate of 3 colonies per hectare. In India at present, there are only 1.2 million colonies. Hence, there is a wide scope for expansion of beekeeping for pollination in India. Crops benefitted by bee pollination are,

- **Fruits and nuts:** Almond, apple, apricot, peach, strawberry, citrus and litchi
- **Vegetable and Vegetable seed crops:** Cabbage, cauliflower, carrot, coriander, cucumber, melon, onion, pumpkin, radish and turnip.
- **Oilseed crops:** Sunflower, rapeseed, mustard, safflower, Sesame.
- **Forage seed crops:** Lucerne, clover.

Why are Bee populations declining?

Bee populations are declining globally due to these combined factors, such as,

a. Habitat loss

Urbanisation and agricultural expansion have destroyed the bees' natural nesting sites and reduced floral diversity, leading to malnutrition.

b. Pesticide usage

Intensive use of agrochemicals acts as major killer. These chemicals impair bees' ability to navigate, forage and reproduce.

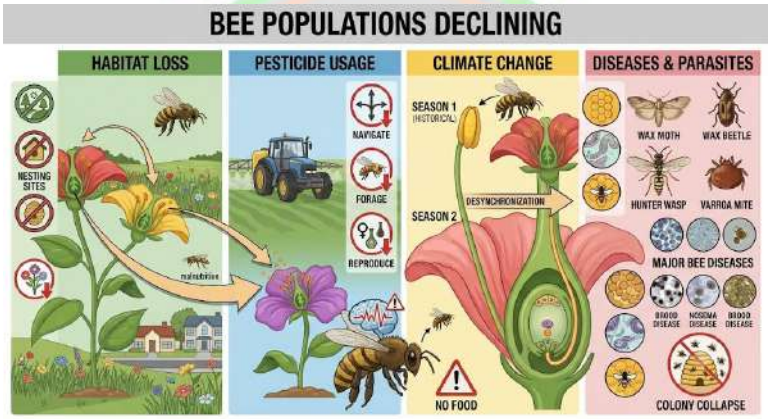
c. Climate change

Rising temperatures disrupt the synchronisation between bee activity and floral bloom times, leaving bees with little to no food.

d. Diseases and parasites

Wax moths, Wax beetles, Bee hunter wasps and *Varroa* mites are the primary insect pests that cause colony collapse.

Brood diseases, Nosema disease and amoebic disease are the major diseases affecting bees.



What happens if Bees disappear?

Without bees, global food production would suffer drastic shortages, leading to a massive loss of nutritious foods like fruits, vegetables and nuts. The cost of food would increase, and the agriculture sector would face immense financial strain due to the loss of key crops. Many flowering plants would die, affecting herbivores that rely on them, subsequently impacting the entire food web. Although other pollinators exist, they are not as efficient or numerous as bees. Artificial pollination techniques (i.e., hand pollination) are too labour-intensive and more costly to replace the efficiency of billions of bees. If bees were to disappear, the global consequences would extend far beyond the loss of honey, triggering severe agricultural and ecological crises. Around 75% of leading food crops depend on animal pollination, meaning their absence would drastically reduce yields of nutrient-dense fruits, vegetables, and nuts, exacerbating global malnutrition. This decline would wipe out hundreds of billions of dollars in agricultural value,

inflating food prices and placing intense financial strain on farmers. Beyond farming, nearly 90% of wild flowering plants rely on pollinators to reproduce; without them, plant populations would collapse, starving herbivores and unravelling entire food webs. Because manual labour and artificial technologies cannot scale to replace the work of billions of insects, protecting bee populations remains essential for global food security and planetary survival.



Small actions, large impact

Small actions can have a major impact on saving declining bee populations, such as,

- Planting native flowers.
- Providing water.
- Support local beekeepers, who practice sustainable beekeeping and provide natural, less processed honey.
- Support organic farming, which reduces pesticide use in agriculture.
- Educate friends, family and relatives about the vital role of bees
- Share information about how to create bee-friendly spaces in your local community.

Conclusion

Pollinators, especially bees, are far more than just tiny visitors to our gardens; they are the backbone of natural ecosystems. From fertilisation in plants to directly influencing the yield and quality of crops, their role is both irreplaceable and invaluable. However, the steady decline in bee populations is a serious warning sign. The consequences of losing bees wouldn't only threaten food security but also disrupt entire ecological balances. The good news is that protecting pollinators doesn't always require large-scale efforts; small conscious actions can collectively make a big difference. Ultimately, protecting pollinators means protecting our own future, ensuring a healthier planet and a more secure food supply for generations to come.

Volume: 06 Issue No: 09

DRONE TECHNOLOGY FOR COASTAL AND WETLAND MONITORING: A SMART TOOL FOR SUSTAINABLE ECOSYSTEM MANAGEMENT

Article ID: AG-V06-I09-59

S.K. Vigneshwaran*, Dr. D. Manimekalai and A. Juliet Selvarani

Department of Aquatic Environment and Management,

Fisheries College and Research Institute, Thoothukudi,

Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Nagapattinam, Tamil Nadu, India

*Corresponding Author: S.K. Vigneshwaran

Introduction

Coastal and wetland ecosystems are among the most productive and biologically diverse environments on Earth. They provide essential ecosystem services, including shoreline protection, carbon sequestration, water purification, flood control, fisheries production, and habitat for numerous plant and animal species. India possesses over 7,500 km of coastline and several ecologically important wetlands, such as the Sundarbans, Chilika Lake, Pulicat Lagoon, Point Calimere, Pichavaram, and Muthupet mangroves. However, these ecosystems are increasingly threatened by urbanization, industrialization, pollution, coastal erosion, climate change, and habitat degradation.

Effective monitoring is essential for conserving these fragile ecosystems. Conventional field surveys are often expensive, labour-intensive, time-consuming, and sometimes impossible in inaccessible areas. Recent advancements in Drone Technology, also known as Unmanned Aerial Vehicles (UAVs), have revolutionized environmental monitoring by providing rapid, accurate, and high-resolution data. Drones have become valuable tools for scientists, environmental managers, and policymakers in monitoring coastal and wetland ecosystems.

What is Drone Technology?

A drone is an unmanned aircraft that operates remotely or autonomously using GPS-based navigation systems. Equipped with high-resolution cameras and advanced sensors, drones can capture aerial photographs, videos, and environmental data over large areas within a short

period. Their ability to fly at low altitudes enables the collection of highly detailed spatial information that is difficult to obtain using satellites or traditional field methods. The most commonly used drones for environmental monitoring include multirotor drones for detailed local surveys, fixed-wing drones for covering extensive coastal regions, and hybrid drones that combine the advantages of both systems.

Applications in Coastal and Wetland Monitoring

Drone technology has become an indispensable tool for monitoring various coastal and wetland environments.

Coastal Mapping and Shoreline Monitoring

Drones produce high-resolution aerial images that accurately map coastlines and detect shoreline changes caused by erosion, sediment deposition, sea-level rise, and storm events. Periodic drone surveys enable authorities to identify vulnerable coastal areas and implement effective coastal protection measures.

Mangrove Assessment

Mangrove forests play an important role in protecting coastal communities, supporting fisheries, and storing carbon. Drone imagery helps estimate mangrove cover, canopy health, biomass, and regeneration status. It also assists in identifying degraded areas requiring restoration.

Wetland Inventory and Habitat Mapping

Wetlands frequently experience seasonal changes in water spread and vegetation. Drone surveys generate detailed maps of wetland boundaries, aquatic vegetation, mudflats, and habitat conditions, supporting biodiversity conservation and sustainable wetland management.

Biodiversity Monitoring

Drones are increasingly used to monitor birds, marine mammals, turtles, and other wildlife with minimal disturbance. High-resolution imagery allows researchers to estimate population sizes, identify nesting sites, and assess habitat quality more efficiently than traditional ground surveys.

Water Quality Assessment

When equipped with multispectral or thermal sensors, drones can help detect changes in water temperature, suspended sediments, algal blooms, and turbidity. These observations support early identification of pollution events and improve water resource management.

Disaster Assessment

Following cyclones, floods, oil spills, or storm surges, drones provide rapid assessment of

affected coastal areas. The collected information helps authorities evaluate damage, plan restoration activities, and improve disaster response.

Applications in Fisheries

Drone technology is becoming increasingly important in fisheries management and aquaculture. It supports mapping of fish habitats, monitoring of estuaries and lagoons, surveillance of aquaculture ponds, assessment of cage culture systems, and detection of illegal fishing activities. Drones also assist in evaluating breeding grounds, nursery habitats, and fish migration routes, contributing to sustainable fisheries management.

Integration with Modern Technologies

The effectiveness of drone technology increases when integrated with modern digital tools.

Geographic Information Systems (GIS) enable spatial analysis and map preparation.

Remote Sensing techniques enhance environmental monitoring over large areas.

Artificial Intelligence (AI) and **Machine Learning** automatically classify land cover, detect habitat changes, and identify environmental anomalies.

Internet of Things (IoT) devices provide real-time environmental information that complements drone observations.

Together, these technologies support data-driven decision-making for ecosystem conservation.

Advantages of Drone Technology

Drone technology offers several advantages over conventional monitoring methods:

- Rapid collection of high-resolution data.
- Cost-effective compared to repeated field surveys.
- Access to remote and hazardous locations.
- Minimal disturbance to wildlife.
- Real-time monitoring capabilities.
- Improved accuracy in habitat mapping.
- Efficient monitoring of environmental changes.
- Better support for conservation planning and resource management.

Challenges

Despite its advantages, drone technology faces several limitations. Limited battery life restricts flight duration and survey area. Strong winds, rainfall, and poor weather conditions reduce operational efficiency. Initial investment costs for advanced drones and sensors can be

high. Skilled personnel are required for flight operations and data processing. In addition, drone operations must comply with national aviation regulations and environmental guidelines.

Future Prospects

The future of drone technology in environmental monitoring is highly promising. Artificial intelligence-powered drones capable of autonomous monitoring are expected to improve ecosystem assessment. Integration with LiDAR, hyperspectral imaging, cloud computing, and real-time data transmission will further enhance monitoring accuracy. Drone swarms may enable simultaneous surveys over extensive coastal regions, while digital twin technologies could support predictive ecosystem management.

In India, increasing government support for Digital India, coastal conservation programmes, wetland restoration initiatives, and Blue Economy policies is expected to expand the use of drones in environmental management.

Conclusion

Drone technology has transformed coastal and wetland monitoring by providing rapid, accurate, and cost-effective environmental information. It enables efficient assessment of shoreline changes, mangrove health, wetland habitats, biodiversity, water quality, and fisheries resources while reducing survey time and operational costs. Although challenges such as battery limitations, weather dependency, and regulatory requirements remain, continuous technological advancements are making drones more reliable and accessible. The integration of drones with GIS, artificial intelligence, remote sensing, and IoT will further strengthen ecosystem monitoring and conservation. Adopting drone technology will play a vital role in protecting India's valuable coastal and wetland ecosystems and ensuring their sustainable management for future generations.

References

Anderson, K., & Gaston, K. J. (2013). Lightweight unmanned aerial vehicles will revolutionize spatial ecology. *Frontiers in Ecology and the Environment*, 11(3), 138–146.

Christofi, D., Mettas, C., Evagorou, E., Stylianou, N., Eliades, M., Theocharidis, C., ... & Hadjimitsis, D. (2025). A review of open remote sensing data with GIS, AI, and UAV support for shoreline detection and coastal erosion monitoring. Applied Sciences, 15(9), 4771.

Duffy, J. P., Cunliffe, A. M., DeBell, L., et al. (2018). Location, location, location: Considerations when using lightweight drones in challenging environments. *Remote Sensing in Ecology and Conservation*, 4, 7–19.

Hodgson, J. C., Baylis, S. M., Mott, R., Herrod, A., & Clarke, R. H. (2016). Precision wildlife monitoring using unmanned aerial vehicles. *Scientific Reports*, 6, 22574.

Klemas, V. (2015). Coastal and environmental remote sensing using unmanned aerial vehicles. *Journal of Coastal Research*, 31(5), 1260–1267.

Long, N., Millescamps, B., Guillot, B., Pouget, F., & Bertin, X. (2016). Monitoring the topography of a dynamic tidal inlet using UAV imagery. Remote Sensing, 8(5), 387.

Volume: 06 Issue No: 09

BIO STIMULANTS FOR ENHANCING OILSEED PRODUCTIVITY AND OIL QUALITY

Article ID: AG-V06-I09-60

S. Yamuna [1*] and A. Sneha[2]

[1*]PG Student, Department of Agronomy, Faculty of Agriculture, Annamalai University, Tamil Nadu, India.

[2]PG Student, Department of Agronomy, Faculty of Agriculture, Annamalai University, Tamil Nadu, India

*Corresponding Author : S. Yamuna

Abstract

Biostimulants are increasingly recognized as important inputs for sustainable oilseed production because of their potential to improve crop growth, nutrient-use efficiency, productivity and produce quality. Oilseed crops are highly responsive to improved physiological activity and nutrient availability, particularly under environmental stresses that limit growth and yield formation. Biostimulants such as seaweed extracts, humic substances, protein hydrolysates, beneficial microorganisms, plant growth-promoting rhizobacteria and mycorrhizal fungi can stimulate root growth, nutrient acquisition, photosynthetic efficiency, enzymatic activity and stress tolerance. Their application through seed treatment, soil application, or foliar spraying can improve plant establishment, biomass production, yield attributes, seed yield and nutrient uptake in several oilseed crops. In addition to productivity enhancement, biostimulants have considerable potential to improve oil accumulation and quality by influencing carbon assimilation, lipid biosynthesis, antioxidant metabolism and fatty acid composition. Positive responses have been reported in major oilseed crops including sunflower, groundnut, rapeseed–mustard, soybean, sesame and safflower. However, the magnitude of response varies with the type and source of biostimulant, formulation, application method, dose, crop genotype, soil characteristics and prevailing environmental conditions. Integrating biostimulants with balanced fertilization and improved crop management can therefore provide a promising approach for

enhancing oilseed productivity while improving resource-use efficiency and resilience to abiotic stresses.

Keywords: Biostimulants, oilseed crops, productivity, oil quality, seaweed extracts, humic substances, nutrient-use efficiency, sustainable agriculture, fatty acids

Introduction

Oilseed crops such as soybean, sunflower, groundnut, mustard, sesame and rapeseed are important contributors to the global edible oil supply, together occupying more than 200 million hectares of cultivated land worldwide. However, yield gains achieved through conventional breeding and fertilization alone have plateaued in many production systems. At the same time, increasing input costs and climate variability continue to reduce farm profitability. Bio stimulants have emerged as a complementary, low dose technology that works alongside conventional nutrient management rather than replacing it. Bio stimulants act as physiological stimulants that influence hormonal balance, root development, nutrient use efficiency and antioxidant defense, enabling plants to perform better under both favorable and stressful conditions. In oilseed crops, these effects can contribute to two important outcomes: increased seed and pod yield and improved oil content and quality.

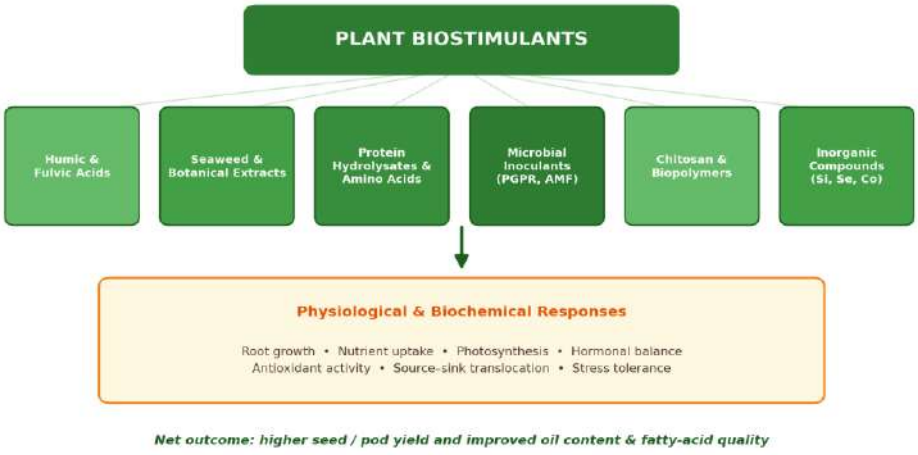


Figure 1. Major categories of plant bio stimulants and their convergent physiological effects on oilseed crops.

Concept of bio stimulants

A plant biostimulant is broadly defined as a formulated product of biological origin, or a substance or microorganism, that, when applied to plants, seeds, or the rhizosphere, stimulates

natural processes that enhance nutrient uptake, nutrient use efficiency, tolerance to abiotic stress and crop quality, independent of its nutrient content (Yakhin *et al.*, 2017). This functional definition, also reflected in the European Union Fertilising Products Regulation (EU 2019/1009), distinguishes bio stimulants from fertilizers and plant protection products, although some commercial formulations may combine biostimulant activity with small amounts of nutrients.

Since bio stimulants are defined by their function rather than their chemical composition, they can be derived from a wide range of raw materials, including marine algae, humified organic matter, protein-rich plant or animal residues, beneficial soil microorganisms, chitin-derived polymers and certain inorganic elements. Oilseed crops are particularly suitable for the application of bio stimulants because their economic value depends on two important traits, namely seed yield and oil quality.

Major Types of Bio stimulants

1. **Humic and Fulvic Acids** - Derived from decomposed organic matter such as peat, lignite and compost; they improve root branching, cation exchange capacity and micronutrient chelation.
2. **Seaweed Extracts** - Extracts from brown algae such as *Ascophyllum nodosum*, *Sargassum* and *Kappaphycus* supply alginates, laminarin, betaines and natural cytokinin-like compounds that promote cell division and delay senescence.
3. **Protein Hydrolysates and Amino Acids** - Produced through the enzymatic or chemical hydrolysis of plant- or animal-derived proteins, these products supply free amino acids and short peptides that act as building blocks for chlorophyll and enzyme synthesis while triggering stress-responsive gene expression.
4. **Microbial Inoculants** -Plant growth-promoting rhizobacteria (PGPR), such as *Azotobacter, Azospirillum* and *Bacillus* species, together with arbuscular mycorrhizal fungi (AMF) and *Trichoderma* spp., improve nutrient solubilisation, phytohormone production and induced systemic resistance.
5. **Chitosan and Biopolymers** -Chitosan, a biopolymer derived from crustacean shell waste, activates plant defense pathways, improves water retention and can be combined with micronutrients for seed treatment.

6. **Beneficial Inorganic Compounds** -Silicon, selenium and cobalt salts, when applied at low concentrations, strengthen cell walls, enhance antioxidant enzyme activity and support nitrogen-fixation efficiency in leguminous oilseed crops.

Mechanisms of Action

Although the six categories of bio stimulants differ widely in their origin, they influence several common physiological and biochemical pathways in plants. Understanding these mechanisms helps explain why the timing and combination of bio stimulants can be as important as the choice of product itself.

Root Architecture Modification: Auxin and betaine-like compounds present in seaweed and humic extracts can stimulate lateral root development and increase root hair formation, thereby expanding the root surface area available for water and nutrient absorption.

Enhanced Nutrient Acquisition: Plant growth-promoting rhizobacteria and mycorrhizal fungi can improve nutrient availability by solubilizing fixed phosphorus, fixing atmospheric nitrogen and facilitating micronutrient acquisition. Humic substances can also improve the cation exchange capacity of the rhizosphere, supporting more efficient nutrient uptake.

Antioxidant and Hormonal Balance: Amino acids, humic substances and microbial signals can enhance antioxidant enzyme activity and regulate plant hormones such as auxin, cytokinin and abscisic acid. These effects help reduce oxidative damage and delay senescence, particularly under stressful conditions.

Support for lipid biosynthesis: Improved leaf longevity and efficient translocation of assimilates can extend the period of active photosynthesis and support fatty acid biosynthesis during seed development, potentially promoting greater oil accumulation in developing seeds.

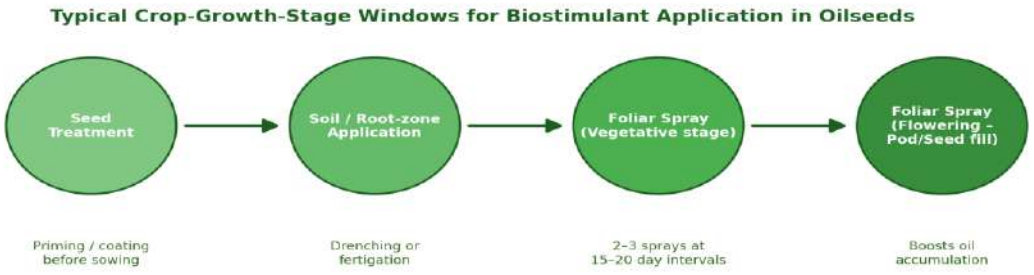


Figure 2. Common growth-stage windows for applying bio stimulants in oilseed crops, from seed treatment through the pod/seed-filling stage.

Application Methods and Management Practices

Field experience and review literature suggest several practical principles for the effective use of bio stimulants in oilseed production. Seed treatment or priming with microbial inoculants and amino acid-based formulations can provide an early advantage in crop establishment. A first foliar application at the four to six leaf or branching stage can support vegetative growth, while subsequent applications around flowering and early pod or seed development may have a greater influence on final oil accumulation.

Combining bio stimulants with mineral fertilizers at reduced rates, rather than relying on the full recommended rate, has shown potential for improving cost effectiveness. This approach reflects the complementary effects of bio stimulants and mineral nutrition rather than their simple substitution.

Beyond routine nutrient management, bio stimulants are increasingly being considered as targeted interventions before anticipated heat or moisture stress, particularly in salt affected or marginal soils. They also have potential applications in organic and reduced input oilseed production systems where the use of synthetic fertilizers is limited.

Effects on Growth, Yield and Oil Quality

Across published field evaluations, biostimulant use is consistently associated with improved stand establishment, deeper and more branched root systems, greater chlorophyll retention during pod filling and better partitioning of assimilates towards developing seeds. These combined effects can contribute to measurable improvements in crop yield. A recent systematic review of soybean trials reported that biostimulant application increased seed oil and protein content by approximately 0.4 to 5.5% and 0.5 to 7.3%, respectively, largely through the optimization of source sink relationships and metabolic pathways during seed filling (soybean systematic review, 2026).

Similar trends have been documented in sunflower, groundnut and mustard, where seaweed extract and humic acid treatments have been associated with improved head and pod filling and higher test weight. A UK focused review of biostimulant products for cereals and oilseed rape also found evidence of yield benefits for most of the product categories evaluated, along with consistent improvements in nutrient uptake and stress tolerance. However, the authors noted that oilseed specific data remain more limited than those available for cereals and that

product performance is strongly influenced by application timing, dose and prevailing weather conditions (AHDB, 2023).

Regarding oil quality, seaweed extracts and protein hydrolysates have been associated with a favorable shift towards unsaturated fatty acids. Humic substances may also improve the availability of micronutrients, particularly boron, zinc and sulfur, which play important roles in oil accumulation and fatty acid biosynthesis.

Practical Approaches and Management

Product Handling: Microbial bio stimulants can be sensitive to storage temperature, soil pH and competition from native microorganisms. Therefore, proper storage and timely application are important for achieving consistent results.

Site Specific Validation: Since bio stimulants act indirectly through various physiological and biological processes, growers should evaluate their performance for at least one complete growing season under their own soil and cultivar conditions before adopting them on a larger scale.

Regulatory Clarity: Regulatory frameworks for bio stimulants are still developing in many parts of the world. Farmers should therefore select products with clearly documented composition and, where available, independent field trial evidence.

Integration Rather Than Replacement: Bio stimulants are generally most effective and economical when integrated with good agronomic practices such as timely sowing, balanced fertilization and proper irrigation management. They should be considered a complementary input rather than a stand-alone solution for poor crop management.

Future Prospects

Research is increasingly focusing on precision timed and crop stage specific biostimulant applications guided by remote sensing and canopy stress indices. This approach could help ensure that biostimulant applications are made when plants are most likely to respond effectively. Nano encapsulation of humic substances and seaweed derived compounds is also being explored to improve foliar absorption and delivery. At the same time, multi omics approaches are helping researchers identify biostimulant combinations that may produce synergistic effects on genes involved in oil biosynthesis rather than simply producing additive responses.Together, these advances indicate that bio stimulants could become an important, data

driven component of oilseed nutrient management, moving beyond their current role as specialized or supplementary inputs.

Conclusion

Bio stimulants offer oilseed growers a scientifically supported, low dose approach to narrow the gap between genetic yield potential and actual farm yield while also improving seed composition through increased oil content and a more favorable fatty acid profile. Although the evidence base is still developing for several oilseed crops, existing research indicates that bio stimulants can provide consistent benefits when applied at the appropriate crop stage, integrated carefully with conventional nutrient management and evaluated under local growing conditions.

Reference

Agriculture and Horticulture Development Board. (2023). *A review of the function, efficacy and value of biostimulant products available for UK cereals and oilseeds*. AHDB.

Benito, P., Celdrán, M., Bellón, J., Arbona, V., González-Guzmán, M., Porcel, R., Yenush, L., & Mulet, J. M. (2025). Use of bio stimulants to enhance waterlogging and flooding tolerance in oilseed crops. In *Bio stimulants for oilseed crops* (pp. 45–68). Springer Nature.

Du Jardin, P. (2015). Plant bio stimulants: Definition, concept, main categories and regulation. *Scientia Horticulturae, 196*, 3–14.

Frontiers in Soil Science. (2025). Seaweed-derived plant boosters: Revolutionizing sustainable farming and soil health. *Frontiers in Soil Science*.

Mirparsa, T., Ganjali, H. R., & Dahmardeh, M. (2016). The effect of biofertilizers on yield and yield components of sunflower oil seed and nut. *International Journal of Agriculture and Biosciences, 5(2),* 46–49.

Rathor, P., González, M., & Príthiviraj, B. (2024). A review of seaweed extract's potential as a biostimulant to enhance growth and mitigate stress in horticulture crops. *Scientia Horticulturae*.

Sustainability. (2026). Role of bio stimulants in sustainable soybean (*Glycine max* L.) production: A systematic review. *Sustainability*, *18*(2), Article 636.

Yakhin, O. I., Lubyanov, A. A., Yakhin, I. A., & Brown, P. H. (2017). Bio stimulants in plant science: A global perspective. *Frontiers in Plant Science, 7*, Article 2049.

Volume: 06 Issue No: 09

THE WHITE GOLD REVOLUTION: TRANSFORMING COTTON PRODUCTION THROUGH TECHNOLOGICAL INNOVATION AND SUSTAINABLE AGRICULTURAL PRACTICES

Article ID: AG-V06-I09-61

Sneha A[1*], Yamuna S [2] and Selvakumar C[3]

[1*, 2 and 3] PG Student, Department of Agronomy, Faculty of Agriculture, Annamalai University, Tamil Nadu, India

*Corresponding Author: Sneha A

Abstract

Cotton popularly known as white Gold is one of the world's most valuable natural fibre crops and plays a significant role in global agriculture, industrial development, and rural livelihoods. More than eighty countries cultivate cotton, supporting millions of farmers while providing raw material for the textile and apparel industries. India possesses the largest area under cotton cultivation and remains one of the leading producers of cotton fibre. However, cotton production faces numerous challenges, including climate change, declining soil fertility, water scarcity, insect pest resistance, rising production costs, and environmental degradation resulting from excessive dependence on synthetic agricultural inputs. These constraints have highlighted the need for innovative and sustainable production systems that enhance productivity while conserving natural resources. Recent technological developments such as precision agriculture, artificial intelligence , Internet of Things , remote sensing, unmanned aerial vehicles , biotechnology, and climate-smart agriculture are revolutionizing cotton cultivation by enabling real time crop monitoring, efficient irrigation, precise nutrient management, and early pest detection. Sustainable practices such as conservation agriculture, integrated pest management, organic farming, regenerative agriculture, and efficient water management further strengthen the resilience of cotton production systems. This review explores the evolution of the White Gold Revolution, recent technological innovations, sustainable production practices, existing challenges, and future prospects for environmentally responsible cotton agriculture.

Keywords: Cotton, White Gold Revolution, Sustainable Agriculture, Precision Agriculture, Artificial Intelligence.

Introduction

Cotton is among the oldest cultivated fibre crops and has played an indispensable role in human civilization for more than five millennia. Archaeological evidence indicates that cotton was cultivated during the Indus Valley Civilization and later spread to different parts of Asia, Africa, Europe, and the Americas. Today, cotton remains the world's leading natural textile fibre and contributes substantially to employment generation, international trade, industrial development, and rural livelihoods. Besides fibre production, cottonseed serves as an important source of edible oil, livestock feed, biodiesel, and several industrial products, making cotton one of the most economically important agricultural commodities globally.India occupies a unique position in global cotton cultivation due to its extensive cultivation area and diverse agro-climatic conditions. Cotton is grown across major cotton-growing states, supporting millions of farming households and the textile industry. However, productivity is constrained by irregular rainfall, declining groundwater availability, pest infestations, nutrient depletion, and fluctuating market prices, necessitating innovative approaches to improve sustainability and resilience . Conventional cotton farming has relied heavily on synthetic fertilizers, chemical pesticides, and intensive irrigation to maximize yields. However, their long-term use has contributed to soil degradation, water pollution, biodiversity loss, greenhouse gas emissions, and increasing production costs. Consequently, sustainable agricultural practices are increasingly promoted to improve productivity while conserving natural resources and protecting environmental quality.The concept of the White Gold Revolution represents the transition towards sustainable and technology-driven cotton production. Precision agriculture, artificial intelligence, remote sensing, UAVs, IoT-enabled irrigation, and biotechnology, integrated with conservation agriculture, integrated pest management, and regenerative farming, enable higher productivity with efficient resource use and reduced environmental impacts.

The White Gold Revolution: A New Era in Cotton Agriculture

The White Gold Revolution refers to the transformation of cotton cultivation from conventional input-intensive farming to a system that integrates technological innovation, environmental sustainability, and economic viability. Earlier improvements through hybrid varieties, chemical fertilizers, irrigation, and genetically modified cultivars increased

productivity but also led to soil degradation, groundwater depletion, biodiversity loss, and higher production costs. Consequently, the modern White Gold Revolution emphasizes sustainable intensification by improving productivity while minimizing environmental impacts (Vitale *et al*., 2024; Tlatla *et al*., 2024).Unlike earlier agricultural revolutions, the present transformation integrates precision agriculture, artificial intelligence (AI), biotechnology, precision irrigation, UAVs, and data-driven decision-support systems to optimize resource use, improve productivity, and enhance climate resilience. Modern cotton production also focuses on conserving natural resources, reducing greenhouse gas emissions, and improving farmers' livelihoods (Getahun *et al*., 2024).Growing consumer demand for sustainable textile products has further accelerated the adoption of responsible cotton production practices, including efficient water management, reduced pesticide use, and traceable production systems, making sustainability a key objective of modern cotton agriculture (Vitale *et al*., 2024).

Global and Indian Scenario of Cotton Production

Cotton is cultivated in approximately eighty countries across tropical and subtropical regions, making it the world's most important natural fibre crop. Major cotton-producing nations include India, China, Brazil, the United States, Pakistan, and Australia. Besides supporting textile industries, cotton contributes significantly to rural employment, export earnings, industrial development, and national economies **(Vitale *et al*., 2024).** India occupies a unique position in global cotton production because it has the largest cultivated cotton area in the world. Cotton is grown predominantly in Gujarat, Maharashtra, Telangana, Andhra Pradesh, Karnataka, Punjab, Haryana, Rajasthan, Madhya Pradesh, and Tamil Nadu. Nevertheless, productivity remains lower than that of several developed countries due to irregular rainfall, fragmented landholdings, insect pest infestations, nutrient deficiencies, and climate variability (Tlatla *et al*., 2024). Climate change has further intensified production challenges by increasing the frequency of droughts, heat waves, erratic rainfall, and pest outbreaks. These factors have highlighted the necessity of developing climate-resilient cotton production systems that combine technological innovations with sustainable agronomic practices. Consequently, governments, research institutions, and international organizations are promoting climate-smart cotton production to ensure long-term productivity and environmental sustainability **(Vitale *et al*., 2024).**

Precision Agriculture: Revolutionizing Cotton Farming

Precision agriculture is a technology-driven approach that uses digital tools such as GIS, GPS, remote sensing, drones, sensors, satellite imagery, and decision-support systems to manage fertilizers, irrigation, and pest control according to crop requirements. This site-specific management improves resource-use efficiency, crop productivity, and farm management (Getahun *et al*., 2024). Precision agriculture also enhances nutrient and water-use efficiency, enables early detection of crop stress and pest infestations, and reduces fertilizer use, pesticide application, labour, fuel consumption, and greenhouse gas emissions. Despite the high initial investment, technological advancements are expected to increase its adoption in sustainable cotton cultivation (Vitale *et al*., 2024).

Artificial Intelligence (AI) in Cotton Production

Artificial Intelligence (AI) has emerged as a transformative technology in modern agriculture by analysing data from satellites, drones, weather stations, soil sensors, and farm machinery to support crop management. By integrating machine learning with real-time field data, AI provides accurate recommendations that improve productivity, optimize resource use, and reduce production risks (Getahun *et al*., 2024). AI-powered image recognition enables early detection of nutrient deficiencies, pests, weeds, and diseases, while machine learning models predict cotton yield, irrigation requirements, weather risks, and pest outbreaks. These technologies support timely management decisions, reduce unnecessary input use, enhance farm profitability, and promote sustainable cotton production (Aierken *et al*., 2024; Getahun *et al*., 2024).

Drone Technology and Remote Sensing in Cotton Farming

Drone technology is widely used in precision cotton farming for rapid crop monitoring. UAVs equipped with RGB, multispectral, hyperspectral, and thermal sensors, together with remote sensing, GIS, and satellite imagery, help detect crop stress, nutrient deficiencies, pests, and water stress, supporting site-specific crop management (Getahun *et al*., 2024). Drones are also used for precision pesticide spraying, enabling targeted chemical application that reduces pesticide use, production costs, and environmental contamination while improving spray efficiency (Vitale *et al*., 2024).

IoT-Based Smart Irrigation

Water scarcity is a major constraint to cotton production, especially in semi-arid regions. IoT-based smart irrigation systems use soil moisture sensors, weather stations, and automated controllers to monitor field conditions and apply water only when required, improving irrigation efficiency and conserving freshwater resources (Vitale *et al*., 2024). The integration of IoT with drip irrigation and smart fertigation further improves water and nutrient-use efficiency, reduces groundwater depletion and production costs, and enhances cotton productivity under climate-smart farming (Getahun *et al*., 2024).

Biotechnology in Cotton Improvement

Biotechnology has significantly improved cotton production through the development of high-yielding, insect-resistant, and climate-resilient cultivars. Bt cotton, developed using *Bacillus thuringiensis* genes, provides effective protection against bollworms and reduces the need for chemical insecticides, thereby increasing productivity and farmers' income (Kranthi & Stone, 2020). Recent advances such as CRISPR-Cas genome editing, RNA interference (RNAi), genomic selection, and marker-assisted breeding are facilitating the development of cotton varieties with improved drought tolerance, disease resistance, heat tolerance, and fibre quality. These modern breeding technologies are expected to enhance climate resilience and sustain cotton productivity under changing environmental conditions (Varshney *et al*., 2023).

Organic Cotton and Regenerative Agriculture

Organic cotton production avoids synthetic fertilizers, chemical pesticides, and genetically modified organisms, relying instead on crop rotation, compost, biofertilizers, and biological pest management to improve soil health, biodiversity, and environmental sustainability (Vitale *et al*., 2024). Regenerative agriculture complements organic farming through practices such as conservation tillage, cover cropping, residue retention, and agroforestry, enhancing soil health, nutrient-use efficiency, climate resilience, and long-term sustainable cotton production.

Integrated Pest Management (IPM)

Integrated Pest Management (IPM) is a sustainable approach to controlling insect pests in cotton by integrating biological, cultural, mechanical, and chemical methods. It reduces reliance on chemical insecticides, minimizes pesticide resistance and environmental contamination, and supports sustainable cotton production (Tlatla *et al*., 2023; Vitale *et al*., 2024). IPM includes the use of natural enemies, crop rotation, resistant cultivars, field sanitation, and traps for effective

pest monitoring and control. Modern IPM also integrates artificial intelligence, remote sensing, drones, and digital advisory platforms for early pest detection and timely management, reducing pesticide use and improving environmental sustainability (Getahun *et al*., 2024).

Climate Change and Climate-Smart Agriculture

Climate change threatens cotton production through rising temperatures, erratic rainfall, droughts, floods, and other extreme weather events, affecting crop growth, fibre quality, and yield (Tlatla *et al*., 2023). Climate-smart agriculture improves resilience through drip and precision irrigation, drought-tolerant cultivars, conservation agriculture, efficient nutrient management, and digital farming technologies, helping sustain cotton productivity under changing climatic conditions (Sami *et al*., 2026).

Major Challenges in Cotton Agriculture

Cotton production is affected by climate variability, drought, soil degradation, declining water resources, and excessive use of chemical fertilizers and pesticides, resulting in reduced productivity, environmental pollution, and higher cultivation costs (Vitale *et al*., 2025). The adoption of advanced technologies such as precision agriculture, drones, AI, and IoT is further constrained by high investment costs, limited extension services, and low digital literacy. Addressing these challenges requires sustainable farming practices, financial support, and farmer capacity building (Vitale *et al*., 2025).

Future Perspectives

The future of cotton agriculture depends on integrating advanced technologies with sustainable farming practices. Precision agriculture, artificial intelligence, machine learning, robotics, satellite monitoring, and digital decision-support systems are expected to improve resource-use efficiency, reduce production risks, and enhance cotton productivity through real-time crop monitoring and management. Future breeding programmes should focus on developing climate-resilient cotton cultivars with improved drought tolerance, heat tolerance, disease and insect resistance, and superior fibre quality using advanced tools such as CRISPR-Cas genome editing, genomic selection, and marker-assisted breeding. Strengthening extension services, farmer training, research investment, and climate-smart policies will accelerate technology adoption and sustainable cotton production. In addition, the growing demand for organic and sustainably certified cotton is expected to create new market opportunities while improving farmers' income and environmental sustainability.

Conclusion

The White Gold Revolution marks a shift towards sustainable and technology-driven cotton production through the integration of precision agriculture, artificial intelligence, drones, IoT, biotechnology, and climate-smart farming. These innovations enhance productivity, improve resource-use efficiency, reduce production costs, and promote environmental sustainability. Despite challenges such as climate change, water scarcity, pest resistance, and soil degradation, continued research, policy support, farmer training, and technology adoption will be essential for ensuring sustainable and resilient cotton production.

References

Aierken, Y., Li, Y., Wang, X., Zhang, H., & Chen, J. (2024). Deep learning applications for crop disease detection and precision agriculture. *Computers and Electronics in Agriculture, 228*, 109697.

Getahun, S., Kefale, H., & Gelaye, Y. (2024). *Application of precision agriculture technologies for sustainable crop production and environmental sustainability: A systematic review*. *The Scientific World Journal*, Article 2126734.

Kranthi, K. R., & Stone, G. D. (2020). Long-term impacts of Bt cotton in India. *Nature Plants, 6*(3), 188–196.

Krishna, V. V., & Qaim, M. (2012). Bt cotton and sustainability of pesticide reductions in India. *Agricultural Systems, 107*, 47–55.

Mellick, Z., Payne, A., & Buys, L. (2021). From fibre to fashion: Understanding the value of sustainability in global cotton textile and apparel value chains. *Sustainability, 13*(22), 12681.

Qaim, M. (2020). Bt cotton, yields and farmers' benefits. *Nature Plants, 6*(11), 1318–1319.

Sandin, G., Peters, G. M., & Svanström, M. (2023). Environmental impacts of cotton and opportunities for improvement. *Nature Reviews Earth & Environment, 4*, 748–764.

Varshney, R. K., Bohra, A., & Roorkiwal, M. (2023). Genomics-assisted breeding for climate-resilient crops. *Nature Reviews Genetics, 24*(8), 512–530.

Vitale, G. S., Scavo, A., Zingale, S., Tuttolomondo, T., Santonoceto, C., Pandino, G., Lombardo, S., Anastasi, U., & Guarnaccia, P. (2024). Agronomic strategies for sustainable cotton production: A systematic literature review. *Agriculture, 14*(9), 1597.

Volume: 06 Issue No: 09

EL NIÑO: IMPACT ON INDIA

Article ID: AG-V06-I09-62

Monaliza Syiemlieh[1] and Dharani Chelladurai[1*]

[1]Department of Agronomy, PGCA, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar-848125, India

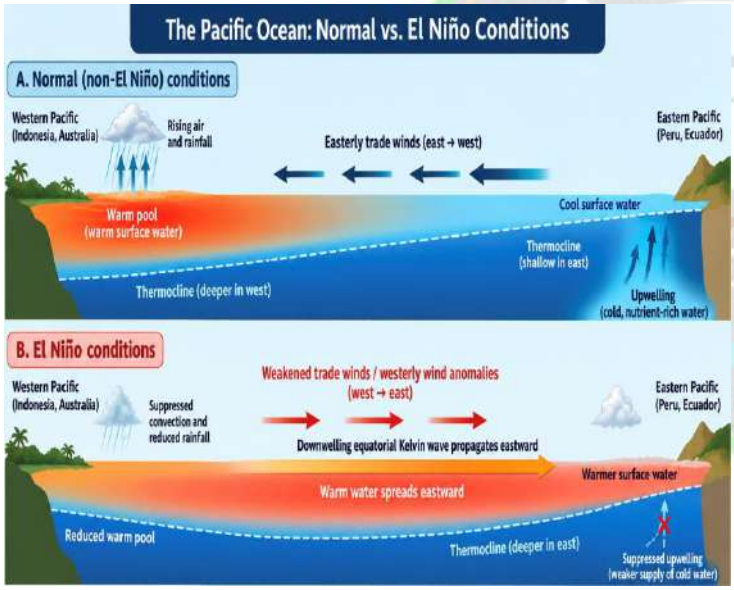
*Corresponding Author: Dharani Chelladurai

Introduction

El Niño has been originally defined as an annual weak warm ocean current that runs southward along the coast of Peru and Ecuador during the winter season particularly during Christmas time hence the name 'Niño' (Spanish for "the boy Christ- child). In modern climate science, El Niño refers to the warm phase of the El Niño–Southern Oscillation (ENSO), a coupled ocean–atmosphere phenomenon centred in the tropical Pacific Ocean. The Southern Oscillation represents the atmospheric component of ENSO and refers to the large-scale seesaw in atmospheric pressure between western and eastern tropical Pacific. The development of many El Niño events is associated with westerly wind anomalies over the western and central equatorial Pacific.

The eastward redistribution of warm upper-ocean water reduces the supply of cold subsurface water to the surface. Consequently, normal cold-water upwelling in the eastern equatorial Pacific is weakened, allowing sea surface temperature (SST) to become unusually warm (Fig.1). The development of El Niño is further strengthened by a positive ocean–atmosphere feedback known as Bjerknes feedback. As the central and eastern Pacific becomes warmer, the normal easterly trade winds weaken. This further reduces upwelling and deepens the thermocline in the eastern Pacific, allowing additional warming of the ocean surface. In this way, oceanic and atmospheric changes reinforce each other and can lead to the rapid growth of an El Niño event. Fig.1 Development of El Niño ENSO does not remain in the El Niño state indefinitely.

Longer-term negative feedback processes help terminate an event and can eventually lead to neutral or La Niña conditions. During the mature stage of an El Niño event, changes in atmospheric forcing can generate off-equatorial Rossby waves that propagate westward. When these disturbances reach the western boundary of the Pacific Ocean, they can contribute to the generation of eastward-propagating equatorial Kelvin waves. These waves can promote thermocline shoaling in the central and eastern Pacific and help restore the normal oceanic cooling processes. Thus, the interaction between positive and delayed negative feedbacks contributes to the oscillating nature of ENSO. ENSO variability is also influenced by external climate forcing and interactions with other climate processes. ENSO has three phases as El Niño, La Niña and ENSO-neutral. El Niño is characterized by anomalous warming of the central and eastern equatorial Pacific Ocean, together with associated changes in atmospheric circulation. La Niña represents the opposite phase, characterized by anomalous cooling of the central and eastern equatorial Pacific. ENSO-neutral conditions occur when Pacific Ocean temperatures and atmospheric circulation remain relatively close to their long-term average state. Not all El Niño events have the same spatial pattern. The traditional or Eastern Pacific (EP) El Niño is characterized by maximum SST warming in the eastern equatorial Pacific. In contrast, Central Pacific (CP) El Niño, also known as a different flavour of El Niño, has its strongest SST anomalies farther west in the central Pacific. In many CP events, the warm central Pacific is surrounded by relatively cooler waters to the east and west. These different El Niño patterns can produce different atmospheric circulation and climate impacts. Through its extensive atmospheric and oceanic teleconnections, ENSO is one of the dominant sources of year-to-year climate variability around the world.



El Niño and its impact on India:

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) reported that global mean surface temperature had increased by 0.74 ± 0.18 °C over the

100-year period from 1906 to 2005. India has also experienced considerable warming, with the all-India mean annual temperature showing an accelerated warming trend during the latter part of the twentieth century. Against this background of long-term warming, natural climate variability such as the El Niño–Southern Oscillation (ENSO) can further influence rainfall and temperature conditions over the country. ENSO is one of the major large-scale climate drivers of year-to-year variability in the Indian summer monsoon. El Niño conditions generally increase the likelihood of a weaker Indian summer monsoon and below-normal rainfall, although the relationship is not one-to-one and the response can vary between individual events and regions. El Niño does not directly cause all Indian droughts; rather, it can increase the probability of drought when its influence is accompanied by unfavourable monsoon circulation and other climate factors.

The combination of El Niño-related rainfall deficits and high temperatures can have important consequences for India. Reduced monsoon rainfall can decrease soil moisture, reservoir levels and water availability, particularly in rainfed agricultural regions. Consequently, severe rainfall deficits during El Niño years can adversely affect the productivity of important crops such as rice, sugarcane, cotton and oilseeds. Reduced agricultural production may, in turn, contribute to food-price pressures and economic losses, particularly when rainfall shortages are widespread and prolonged. Thus, understanding ENSO is important for agricultural planning, water-resource management and preparedness for drought conditions.

El Niño events commonly develop during boreal spring and summer, strengthen during the latter part of the year and generally reach their peak intensity during boreal winter, around November–January. In contrast, La Niña, the cool phase of ENSO, is generally associated with normal to above-normal Indian summer monsoon rainfall. However, La Niña does not guarantee excess rainfall across the entire country, as the monsoon response is also influenced by other oceanic and atmospheric processes. The Indian Ocean Dipole (IOD), intraseasonal atmospheric variability and other regional and global climate factors can strengthen, weaken or modify the ENSO–monsoon relationship. ENSO can also influence temperature conditions over India. El Niño-related atmospheric circulation changes may contribute to warmer-than-normal conditions in certain seasons and regions. These effects occur against a background of long-term climate warming, which has been observed in both daytime and nighttime temperatures over India. Temperature extremes are an important component of climate variability and climate change, and increasing temperatures can raise the likelihood of heat extremes. Globally, observations

indicate a general increase in the frequency and intensity of warm extremes and a decline in many cold extremes. The influence of ENSO therefore extends far beyond the tropical Pacific Ocean. Through its global atmospheric and oceanic teleconnections, ENSO can affect rainfall, temperature, agriculture, water resources and economies in distant regions. It is widely recognized as the dominant mode of year-to-year climate variability globally. For India, understanding the interaction between ENSO, the Indian monsoon and the country's changing climate is particularly important for improving seasonal climate prediction, agricultural decision-making and preparedness for climate-related risks.

References

Trenberth, K. E. (1997). The definition of el nino. *Bulletin of the American Meteorological Society*, *78*(12), 2771-2778.

Enfield, D. B. (1989), *El Niño, past and present*, *Rev. Geophys.*, 27(1), 159–187, doi:10.1029/RG027i001p00159.

Revadekar, J. V., Kothawale, D. R., & Rupa Kumar, K. (2009). Role of El Niño/La Niña in temperature extremes over India. *International Journal of Climatology*, *29*(14), 2121.

Yeh, S. W., Kug, J. S., Dewitte, B., Kwon, M. H., Kirtman, B. P., & Jin, F. F. (2009). El Niño in a changing climate. *Nature*, *461*(7263), 511-514.

Volume: 06 Issue No: 09

VALUE ADDITION IN BANANA FOR RURAL EMPLOYMENT GENERATION

Article ID: AG-VO6-I09-63

M.Marimuthu

Krishi Vigyan Kendra, Sirugamani, Trichy- 639 115, Tamil Nadu, India

Introduction

India is the world's largest producer of bananas, contributing significantly to national fruit production and rural livelihoods. Despite its importance, banana is highly perishable and prone to rapid spoilage, leading to substantial post-harvest losses, especially during peak harvest seasons and market gluts. This makes value addition an essential strategy to enhance the economic reliability of banana cultivation. By converting raw bananas into a variety of processed products such as chips, flour, puree, beverages, fibre materials, and eco-friendly packaging, value addition extends shelf life, improves marketability, and opens new income avenues for farmers, small-scale processors, and rural entrepreneurs. It not only supports better utilization of surplus and low-grade fruits but also contributes to employment generation, waste reduction, and sustainable agricultural development. Therefore, value addition in banana plays a vital role in strengthening the entire banana value chain and ensuring greater economic returns to producers.

Objectives of Value Addition in Banana

1. To minimize post-harvest losses by converting perishable bananas into shelf-stable processed products.
2. To enhance farmers' income by improving market value and creating profitable product lines.
3. To diversify banana-based products such as chips, flour, puree, beverages, and fibre items for domestic and export markets.
4. To improve shelf life and storage stability of ripe and raw bananas through processing and preservation.
5. To utilize surplus, undersized, and low-grade fruits that are otherwise unmarketable in the fresh fruit market.

6. To promote rural entrepreneurship and employment through small-scale processing units and women-led SHGs.

7. To increase nutritional availability by developing nutritious and functional foods like banana flour and baby foods.

8. To meet changing consumer preferences for ready-to-eat (RTE) and ready-to-serve (RTS) banana-based products.

9. To expand export potential through standardized, high-quality processed banana products.

10. To encourage efficient utilization of by-products such as pseudostem fibre, leaves, and peels for eco-friendly products.

Nutritional Importance of Banana

Banana is highly valued for its rich nutritional composition and easy digestibility, making it an important energy-giving fruit. It contains a high amount of carbohydrates in the form of starch and natural sugars, which provide instant energy. Bananas are an excellent source of potassium, a vital mineral that helps regulate blood pressure, maintain electrolyte balance, and support muscle and nerve function. They are also rich in dietary fiber that aids digestion and promotes gut health. Vitamins such as vitamin B6, vitamin C, and small amounts of vitamin A contribute to metabolic functions, immunity, and antioxidant defense. Additionally, bananas contain bioactive compounds like phenolics and resistant starch, which have functional and health-promoting properties. Owing to this strong nutritional profile, bananas are widely used in therapeutic diets, infant foods, and nutraceutical products.

Major Value-Added Products of Banana

Banana can be processed into a wide range of value-added products that not only extend shelf life but also enhance market value and consumer acceptability. These products utilize both ripe and unripe fruits, as well as the plant's by-products, thereby ensuring complete utilization of the crop. The major value-added products of banana include the following:

1. Banana Chips: Made from mature unripe bananas, banana chips are one of the most popular traditional snack foods. They are prepared by slicing, frying, and seasoning the fruit. Their long shelf life and high demand make them an important commercial product.
2. Banana Wafers: These are thin, crispy slices of raw banana processed using mechanical slicers. They are often vacuum-fried or baked and have a growing market in the snack industry, including exports.

3. Banana Powder / Flour: Prepared from dehydrated unripe bananas, banana flour is rich in resistant starch and used in bakery products, baby foods, porridges, and gluten-free diets. It has high export potential due to its functional food properties.

4. Banana Puree / Pulp: Ripe bananas are processed into smooth puree or pulp, which serves as a base ingredient for baby foods, ice creams, bakery fillings, juices, and smoothies.

5. Banana Jam and Jelly: These sweet spreads are made from ripe banana pulp and sugar. They are widely used in confectionery and bakery items and offer a simple, small-scale processing opportunity.

6. Banana Juice / Nectar / RTS Beverages: Bananas can be processed into ready-to-serve beverages, juice blends, and nectar, offering a refreshing and nutritious drink alternative. These beverages have steady demand in the fruit drink industry.

7. Banana Candy / Bar / Toffee: Made by cooking ripe banana pulp with sugar and flavors, banana candies and bars are popular among children and provide a long-lasting way to use fully ripe bananas.

8. Banana Wine and Fermented Products: Ripe bananas can be fermented to produce wine, vinegar, alcohol, and probiotic beverages. These products add premium value and are increasingly explored for entrepreneurship.

9. Banana Fibre Products: Fibre extracted from the pseudostem is used to manufacture eco-friendly products such as ropes, mats, paper, textiles, and handicrafts. This supports sustainability and additional farmer income.

10. Banana Leaf Plates and Packaging Materials: Banana leaves are used to make biodegradable plates, cups, and food containers. With growing demand for eco-friendly packaging, these products have strong market potential.

Economic Importance

Value addition in banana plays a crucial role in strengthening the rural economy and enhancing the profitability of banana cultivation. Processing bananas into chips, flour, puree, beverages, and fibre-based products significantly increases the shelf life and market value of the fruit, thereby reducing post-harvest losses and stabilizing farmer incomes. It promotes the utilization of surplus, damaged, or undersized fruits that otherwise fetch low prices in the fresh market. The development of small- and medium-scale processing units generates employment opportunities, especially for rural youth and women's self-help groups, contributing to

entrepreneurship and livelihood security. Value-added banana products such as chips, flour, and leaf-based plates have strong domestic demand and increasing export potential, further boosting foreign exchange earnings. Additionally, by-products like pseudostem fibre, leaves, and peels create supplementary income sources and support eco- friendly industries. Overall, value addition enhances economic resilience, encourages innovation, and strengthens the entire banana value chain.

Conclusion

Value addition in banana offers immense potential to enhance income, reduce post-harvest losses, and support sustainable utilization of the crop. By converting perishable fruits into high-quality processed products such as chips, flour, puree, beverages, and fibre-based items, farmers and entrepreneurs can tap into expanding domestic and export markets. The availability of diverse technologies and processing methods enables the efficient use of ripe, unripe, and even low-grade fruits, contributing to waste reduction and improved profitability. Moreover, value addition encourages rural entrepreneurship, promotes employment generation, and strengthens the overall banana value chain. With proper training, infrastructure, and market linkages, banana value addition can become a key driver of economic growth and rural development.

Volume: 06 Issue No: 09

MODERN FISHERIES SURVEILLANCE: INTEGRATION OF DRONES INTO INDIAN MARINE FISHERIES PATROLS

Article ID: AG-V06-I09-64

Shahana S.[1*] and Silpa S.[1]

[1]Ph.D., Department of Fisheries Resource Management, ICAR-CIFE, Mumbai, India

*Corresponding Author : Shahana S.

Abstract

Integrating modern technologies into fisheries management allows us to tackle Illegal, Unreported and Unregulated (IUU) fishing to a greater extent. Maritime surveillance heavily relies on crewed patrol vessels traditionally. Integration of Unmanned Aerial Vehicles(UAVs), such as drones, into maritime patrol overcomes major hurdles faced by traditional crewed vessel patrols at sea. Drone-integrated operations offer low operational cost, rapid response time, wide area coverage, silent operations at high altitudes and continuous telemetry feeds. Even though battery and endurance limits, rough weather conditions, the requirement of legal coordination with civil aviation and data processing bottlenecks remain major challenges faced in the deployment of drones, this technology will proactively support fisheries patrolling. Drone-based monitoring is already being utilised by the Department of Fisheries, Maharashtra, India.

Key words: Drones. Fisheries, Patrol, Surveillance, Marine, India

Introduction

Fisheries patrolling is the activity of monitoring and inspection of water bodies by using vessels, air support or any other means to combat illegal fishing.[1] Conventionally, patrolling is carried out using crewed vessels across coastal and offshore waters to enforce maritime laws. [2] For effective coastal patrolling, pre-deploying small patrol boats near heavy fishing areas allows faster responses and continuous monitoring of resources. But for offshore fishing areas, integration of aerial surveillance serves as the core capability in detecting unlicensed fishing operations and area violations.[3] Vessel patrolling at sea faces high acquisition and operational costs, as they are very expensive to run, cover only a small area, and experience frequent

downtime caused by adverse weather or routine maintenance. As large patrol boats are slow and easy to spot, illegal fishers can easily avoid them or wait until they leave. Despite all this, patrol vessels remain indispensable enforcement tools whose operations and surveillance can be optimised with the integration of air patrol.[4] Air surveillance in fisheries uses maritime patrol aircraft, planes, helicopters and Unmanned aerial vehicles (UAVs) such as Drones.[5]

Drones are a modern, safer, cost-effective and faster way to collect data from remote areas compared to traditional piloted aircraft.[6] Drone technology includes various designs such as fixed-wing, rotary-wing, and hybrid models, equipped with cameras, sensors and GPS systems, controlled via remote mechanisms.[7] From being a remotely controlled aerial aircraft used for training purposes in World War I, drone technology expanded rapidly beyond defence into diverse fields such as precision agriculture, professional cinematography, infrastructure inspection and environmental monitoring.[8] Drones serve a vital lifesaving role by enabling the rapid aerial delivery of essential medical supplies to remote and isolated regions in developing nations during critical health emergencies.[9]

Applications of Drones or UAVs in Fisheries

Recreational Angling and Fish Scouting: Drone Fishing is a version where lines are transported to areas of fish availability using drones. Drones provide real-time scouting capabilities, allowing anglers to pinpoint optimal fishing zones and critical habitats.[10]

Population Tracking and Assessment: UAVs integrated with high-resolution imagery and advanced sensors allow tracking of school movements and assessment of fish populations, causing minimal disturbance to marine life. Currently, drone-based studies on marine fauna rely primarily on standard RGB sensors.[11]

Habitat and Ecosystem Mapping: Drones enable detailed mapping of coastal and aquatic habitats. They can generate bathymetric and turbidity maps in freshwater systems. They effectively capture essential data on breeding grounds, feeding areas, coral reef ecosystems and environmental threats. [12-14]

Oceanographic Profiling: Drones gather data on sea surface temperature, chlorophyll levels, and ocean currents, which can track fish migration routes and distribution patterns.[15]

Automated Water Quality Monitoring: Drones monitor key water quality factors like temperature, salinity, turbidity, and nutrients in real time, allowing us to take immediate action in response to changes in the aquatic environment. Additionally, drones can connect underwater

stereo and sonar cameras to cloud-based AI, automating fish counting and length estimation. [16-17]

Jellyfish Swarm Enumeration: Drones economically survey vast swarms of jellyfish.[18]

Harmful Algal Bloom (HAB) Detection and Early Warning: Drones survey the sea surface and collect water samples, helping in early detection of Harmful Algal Blooms through Microscopic image analysis and sending automated alerts. [19-20]

Hazardous and Remote Water Sampling: Drones can safely collect environmental samples from remote or dangerous areas. [21-22]

Fisheries Surveillance and IUU Enforcement: Automated Surveillance blending smart sensors and computer vision to scale up Monitoring, Control, and Surveillance (MCS) operations through real-time aerial drone deployment delivers a proactive defence against IUU fishing not only in marine protected areas but also in oceanic marine regimes.[23]

Drones in marine fisheries surveillance of India

India's first and only state to implement drone-based surveillance to enforce the Marine Fishing Regulation Act is Maharashtra. Fisheries Department has deployed nine drones in the coastal districts – Thane (1), Raigad (2), Ratnagiri (4) and Sindhudurg (2) in 2025. Beyond monitoring, the footage and information captured will be used directly as legal evidence to track down unauthorised boats.[24] All penalties and legal punishments are enforced in accordance with the Marine Fishing Regulation (Amendment) Act, 2021. To further tighten security along the coast and stamp out illegal fishing, Maharashtra Fisheries and Ports Minister Nitesh Rane has ordered the procurement of 10 more surveillance drones in April 2026.[25]

The state monitors fishing activities through a strategic alliance with ideaForge Technology Limited and Schnell Drone Technologies Ltd., deploying cutting-edge UAV technology. They use ideaForge's SWITCH UAVs for their high precision and operational durability in maritime environments. The SWITCH UAV is a hybrid UAV combining fixed-wing and Vertical Take-Off and Landing, designed for long-range, high-endurance and high-altitude missions, offering extended flight times, enhanced safety features, fail-safe redundancies, along with simple operations. These UAVs endure extreme temperatures and all terrains, executing high-altitude, day-and-night intelligence, surveillance, and reconnaissance (ISR) operations in harsh environments. Its lightweight, portable design and toolless snap-fit assembly make it ideal for convenient transport and deployment. The SWITCH UAV supports

advanced payloads, including a 25x HD optical zoom camera with a 1,000-meter target detection range and a 640x480 thermal camera featuring 4x digital zoom that provides effective target detection up to 500 meters. It features an advanced autopilot system that supports both remote-controlled piloting and fully autonomous flights. The BlueFire Touch Ground Control Station makes it easier to use the Switch UAV with helpful features such as Over the Hill Tracking via Airborne Data Relay (ADR) and Remote Video Terminal (RVT), launch-site terrain analysis for accurate operational area calculations, use of custom maps to plan your route, a replay tool that shows past flights together with the drone's video and also allows users to instantly mark important spots on the map and share the coordinates. The partner company provides skilled drone pilots to support the department across each district.[26]

Strategic Advantages and Challenges of drone patrolling in marine fisheries

Combining vessel patrols with simultaneous drone flights enables the precise tracking of unauthorised fishing vessels and enables immediate apprehensions. Expanded operational reach, cost efficiency, and real-time data access are the key benefits of drones in marine fisheries due to the large and remote area of monitoring and harsh environmental and oceanographic conditions. Drones carry out eco-friendly monitoring, generating negligible emissions and physical disturbance. These drones also support emergency search-and-rescue operations at sea. As the area to cover in marine ecosystems is large, flight duration, sensor accuracy, and payload capacity remain bottlenecks. Drone surveillance of fishing operations in Mumbai and Mumbai Suburban districts is not permitted due to regulatory compliance. Thermal photographs generated during night surveillance are not reliable for enforcement, as they do not display the name and registration number of vessels and may lead to misinterpretation of gear or vessels. Flights require fair weather, which makes it difficult to operate during high wind speeds and harsh environments, which are frequently expected in the marine realm.

Way forward

New technologies like artificial intelligence may automatically detect illegal, unreported, and unregulated (IUU) fishing vessels in real time without requiring constant human monitoring of video feeds, which will enable drones to become even more efficient and effective. As technology develops, increases in flight duration, payload capacity, and sensor accuracy are predictable. Advances in battery capacity and propulsion technology are expected to significantly extend drone endurance and support longer continuous patrols along the coastline. Drones will

likely support heavier and more robust sensor suites without sacrificing speed or manoeuvrability. Enhanced sensor precision will enable clearer imaging, more reliable target detection, and better data collection even in challenging marine environments. The use of UAVs for the surveillance of various aquatic ecosystems should be promoted and adopted by the other states of India, as it is a sustainable tool for fisheries and aquatic resource management.

References

1. Kastoryano, S., & Vollaard, B. (2023). Unseen annihilation: Illegal fishing practices and nautical patrol. *Journal of Environmental Economics and Management*, *122*, 102881.
2. Flewwelling, P., Cullinan, C., Balton, D., Sautter, R. P., & Reynolds, J. E. (2002). Patrols, boardings, inspections and prosecution (Chap. 7). In Recent trends in monitoring, control and surveillance systems for capture fisheries (FAO Fisheries Technical Paper No. 415, pp. 119–137). Food and Agriculture Organization of the United Nations.
3. Flewwelling, P. (1994). MCS operational procedures. In *An introduction to monitoring, control and surveillance systems for capture fisheries* (Ch. 5). Food and Agriculture Organization of the United Nations. fao.org
4. Bergh, P. E., & Davies, S. (2002). Chapter 8: Fishery monitoring, control and surveillance. In K. L. Cochrane (Ed.), *A fishery manager's guidebook: Management measures and their application* (FAO Fisheries Technical Paper No. 424, pp. 175–204). Food and Agriculture Organization of the United Nations.
5. Uddin, M. S. (2026). A Drone System With Vison for Fishing Activity Detection. In *Enhancing Surveillance With Blockchain and IoT Drone Technology* (pp. 41-78). IGI Global Scientific Publishing.
6. Pan, Z. F., An, L., & Wen, C. Y. (2019). Recent advances in fuel cells based propulsion systems for unmanned aerial vehicles. *Applied Energy*, *240*, 473-485.
7. Austin, R. (2011). *Unmanned aircraft systems: UAVS design, development and deployment*. John Wiley & Sons.
8. Abuthagir Iburahim, S., Ashpel Mano, M. R., Naga Kalpithashree, N., Ananthan, P. S., & Arisekar, U. (2025). Drones or unmanned aerial vehicles in fisheries and aquaculture. In *Information Technology in Fisheries and Aquaculture* (pp. 279-293). Singapore: Springer Nature Singapore.

9. Emimi, M., Khaleel, M., & Alkrash, A. (2023). The current opportunities and challenges in drone technology. *Int. J. Electr. Eng. Sustain.*, *1*(3), 74-89.
10. Winkler, A. C., Butler, E. C., Attwood, C. G., Mann, B. Q., & Potts, W. M. (2022). The emergence of marine recreational drone fishing: Regional trends and emerging concerns. *Ambio*, *51*(3), 638-651.
11. Letnes, P. A., Hansen, I. M., Aas, L. M. S., Eide, I., Pettersen, R., Tassara, L., ... & Bytingsvik, J. (2019). Underwater hyperspectral classification of deep sea corals exposed to 2-methylnaphthalene. *PloS one*, *14*(2), e0209960.
12. Kopaska, J. (2014). Drones—a fisheries assessment tool?. *Fisheries*, *39*(7), 319-319.
13. Casella, E., Collin, A., Harris, D., Ferse, S., Bejarano, S., Parravicini, V., ... & Rovere, A. (2017). Mapping coral reefs using consumer-grade drones and structure from motion photogrammetry techniques. *Coral Reefs*, *36*(1), 269-275.
14. Koparan, C., Koc, A. B., Privette, C. V., & Sawyer, C. B. (2020). Adaptive water sampling device for aerial robots. *Drones*, *4*(1), 5.
15. Toonen, H. M., & Bush, S. R. (2020). The digital frontiers of fisheries governance: fish attraction devices, drones and satellites. *Journal of environmental policy & planning*, *22*(1), 125-137.
16. Ubina, N. A., Cheng, S. C., Chen, H. Y., Chang, C. C., & Lan, H. Y. (2021). A visual aquaculture system using a cloud-based autonomous drones. *Drones*, *5*(4), 109.
17. Aung, T., Abdul Razak, R., & Rahiman Bin Md Nor, A. (2025). Artificial intelligence methods used in various aquaculture applications: A systematic literature review. *Journal of the World Aquaculture Society*, *56*(1), e13107.
18. Zhang, F., Wang, S., Qiu, Y., Wang, N., Sun, S., & Bi, H. (2025). A Novel UAV-and AI-Based Remote Sensing Approach for Quantitative Monitoring of Jellyfish Populations: A Case Study of Acromitus flagellatus in Qinglan Port. *Remote Sensing*, *17*(17), 3020.\
19. Kimura, F., Morinaga, A., Fukushima, M., Ishiguro, T., Sato, Y., Sakaguchi, A., ... & Kobayashi, T. (2019). Early detection system of harmful algal bloom using drones and water sample image recognition. *Sensors and Materials*, *31*(12), 4155-4171.
20. Byrd, K., Wu, J., & Lee, J. (2025). Harmful Algal Bloom Monitoring with Unmanned Aerial Vehicles: Tools, Challenges, and Public Health Implications. *Toxins*, *17*(10), 475.

21. Castendyk, D. N., Straight, B. J., Voorhis, J. C., Somogyi, M. K., Jepson, W. E., & Kucera, B. L. (2019). Using aerial drones to select sample depths in pit lakes. In *Mine closure 2019: Proceedings of the 13th international conference on mine closure* (pp. 1113-1126). Australian Centre for Geomechanics.
22. Grandy, J. J., Galpin, V., Singh, V., & Pawliszyn, J. (2020). Development of a drone-based thin-film solid-phase microextraction water sampler to facilitate on-site screening of environmental pollutants. *Analytical chemistry*, *92*(19), 12917-12924.
23. Klein, N. (2024). The Use of Maritime Autonomous Vehicles in Fisheries Law Enforcement. In *Maritime Autonomous Vehicles and International Law* (pp. 253-272). Routledge.
24. https://indianexpress.com/article/cities/mumbai/govt-launches-drone-based-system-monitor-illegal-fishing-coastline-9770168/
25. https://www.freepressjournal.io/mumbai/maharashtra-minister-nitesh-rane-orders-10-more-drones-to-boost-coastal-surveillance-crack-down-on-illegal-fishing
26. https://ideaforgetech.com/security-and-surveillance/switch-uav

Volume: 06 Issue No: 09

SENSOR-BASED PROCESS MONITORING AND AUTOMATION IN GRAIN MILLING

Article ID: AG-V06-I09-65

Anjana K and Ravindra Naik*

ICAR Central Institute of Agricultural Engineering, Regional Station, Coimbatore – 641 007

Tamil Nadu, India

*Corresponding Author: Ravindra Naik

Introduction

Grain milling is a process that has evolved from simple stone grinding to highly automated industrial systems capable of processing several tonnes of grain per hour. Although the basic objective remains the same, to transform grain into useful products such as flour, meal, semolina or polished grain, the modern milling industry demands much greater control over quality, energy consumption, productivity and food safety. Wheat, rice, maize, sorghum and other grains pass through several operations including reception, cleaning, conditioning, grinding, separation, conveying, blending and packaging. At every stage, the characteristics of the grain and the operating conditions of the equipment influence the final product. A miller traditionally relies on experience, observation and laboratory measurements to maintain process performance. These skills remain extremely important. However, the increasing scale and complexity of modern mills make continuous measurement increasingly valuable. This is where sensor technology becomes important (Figure 1).

A sensor converts a physical or chemical property into a measurable signal. Temperature sensors measure heat, pressure sensors measure pressure, moisture sensors estimate water content, vibration sensors monitor mechanical behaviour, and optical or NIR sensors provide information about material characteristics. When these sensors are connected to an automated control system, the mill can continuously monitor what is happening and, in some cases, automatically adjust the process. The basic concept is:

Sense → Measure → Analyse → Decide → Control

This simple sequence is at the heart of the transition towards smart milling. Thus, sensor-based monitoring and automation are transforming conventional grain mills into more efficient, consistent and data-driven processing systems.

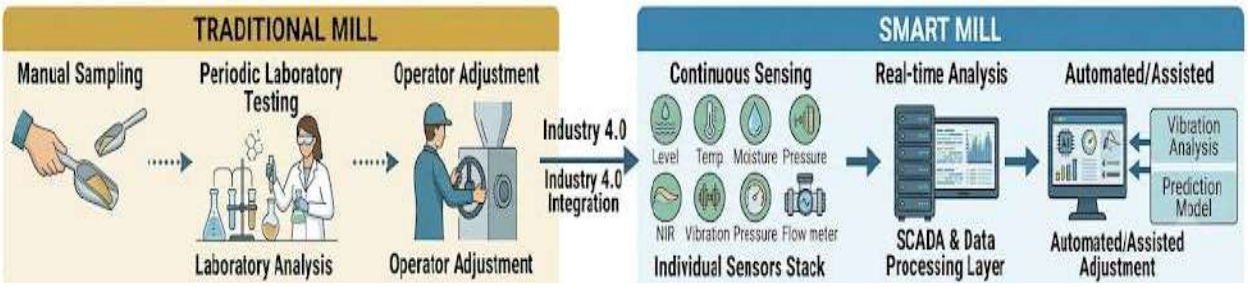


Figure 1: Traditional milling vs. Smart milling

Why sensors are Important in Grain Milling?

The quality and efficiency of grain milling depend on both the characteristics of the raw material and the operating conditions of the process. Parameters such as moisture, temperature, particle size, protein content, impurities and machine condition can influence milling performance and final product quality.

Among these, moisture is particularly important. In wheat milling, conditioning or tempering adjusts grain moisture before grinding, influencing grain breakage, bran separation, endosperm recovery and flour yield. Moisture can be monitored using electrical, dielectric and optical sensing techniques. Other sensors provide complementary information: temperature sensors monitor equipment and process conditions, vibration sensors indicate the condition of rotating machinery, level sensors help manage grain in bins and hoppers, while pressure and flow sensors monitor pneumatic conveying and aspiration systems. Optical and spectroscopic sensors can also provide rapid information about grain and flour composition. Continuous sensing enables mills to detect changes earlier than periodic sampling alone and respond before they significantly affect product quality or equipment performance. The fundamental principle is simple: Measure → Understand → Control → Improve.

Essential sensors used in grain milling

Modern grain milling relies on a variety of specialized sensors to optimize production and ensure safety, as detailed below.

1) Moisture Sensors

Among all the properties measured in grain processing, moisture is one of the most zimportant. Grain moisture influences handling, storage, conditioning and milling behaviour. However, moisture cannot be judged reliably simply by looking at the grain.

Traditional laboratory methods can provide accurate measurements but may require sampling, preparation and time. For a modern continuous process, there is a strong advantage in obtaining measurements rapidly and, where appropriate, directly in the production line.

How do moisture sensors work?

Electrical and dielectric methods determine moisture indirectly by measuring electrical properties of the grain. The relationship between these electrical properties and moisture depends on factors such as temperature, grain type, density and frequency. Consequently, appropriate calibration is important.

Optical methods, particularly NIR spectroscopy, provide another approach. NIR sensors illuminate the material with near-infrared radiation and analyse the resulting spectral response. Because water and other components interact with light in characteristic ways, calibrated models can relate spectral information to moisture and other quality parameters.

Why is real-time measurement useful?

Imagine a mill receiving grain whose moisture is gradually changing. Without continuous measurement, the operator may discover the change only after laboratory analysis or after observing a change in milling behaviour. With an online sensor, the change can be detected much earlier. This information can support adjustments to conditioning, blending or other process parameters. Thus, the sensor is not simply measuring moisture. It is helping the mill maintain a stable process.

2) Near-infrared (NIR) Sensors

One of the most interesting developments in grain and flour processing is the use of near-infrared (NIR) spectroscopy. NIR technology has attracted considerable attention because it can provide rapid, non-destructive information about the composition of agricultural materials. In flour milling, NIR systems can be used to monitor parameters including moisture, protein and ash. Industrial applications describe their use for real-time quality control during milling and mixing.

What makes NIR different?

Conventional laboratory analysis generally involves collecting a sample and carrying it to a laboratory. An online NIR sensor can instead be positioned near the production process. The measurement principle can be represented simply as:

Grain/flour → NIR illumination → spectral response → calibration model → estimated quality parameter

The sensor does not directly "see" protein or moisture in the same way that a human sees colour. Instead, it measures spectral information and uses mathematical calibration models to estimate the desired property. This distinction is important. NIR is a measurement technology that depends on appropriate calibration and validation. Its performance can vary with material characteristics and operating conditions.

Depending on the application and calibration, NIR systems can provide information about moisture, protein, ash, fat and other constituents in appropriate materials, selected quality characteristics. NIR reviews also identify its ability to provide rapid, non-destructive measurements of chemical composition in grain and agricultural materials

3) Temperature Sensors

Temperature sensors are among the simplest sensors used in an industrial plant, but their role can be extremely valuable. A milling plant contains many moving components such as motors, bearings, rollers, gearboxes, fans, conveyors, pneumatic equipment etc. Mechanical friction, overloading, inadequate lubrication or component damage can cause temperature to rise.

A temperature sensor provides an early indication that something may be changing. For example, if the temperature of a bearing gradually increases above its normal operating range, the control system can generate an alarm. Maintenance personnel can then inspect the equipment. Temperature monitoring therefore contributes to condition monitoring and preventive maintenance. It can also be important for the product itself. Excessive heat generated during processing can affect product characteristics and energy efficiency.

4) Vibration Sensors

A machine can often reveal its mechanical condition through vibration. Every rotating machine produces some vibration. The important question is not whether vibration exists, but whether its magnitude or pattern changes from normal operation. Vibration sensors can be installed on motors, bearings, fans and other rotating equipment. A simplified condition-

monitoring concept is: Normal vibration → establish baseline → continuous measurement → detect deviation → inspect equipment.

A significant change may indicate, bearing deterioration, shaft misalignment, rotor imbalance, mechanical looseness, abnormal loading etc. The sensor does not necessarily identify the exact fault by itself. Instead, it provides information that can trigger further diagnosis. This is an important principle in modern automation, sensors provide evidence; engineering knowledge converts that evidence into action.

5) Level Sensors

Grain mills contain storage bins, hoppers and intermediate containers. If a hopper becomes empty, downstream machinery may operate without sufficient material. If it becomes overfilled, the process may be interrupted. Level sensors help maintain an appropriate material inventory. Depending on the application, technologies may include, ultrasonic sensors, radar sensors, capacitive sensors and mechanical level switches. The choice depends on the material, vessel geometry, dust conditions, measurement range and required accuracy. In a large automated mill, level measurements can be integrated with programmable logic controllers (PLCs) and supervisory control systems. The result is coordinated movement of grain through the plant.

6) Flow and Pressure Sensors

Grain milling is also a material-flow problem. Grain and flour move through conveyors, ducts, pipes and pneumatic conveying systems. Airflow is particularly important in aspiration and pneumatic transport. Pressure sensors can help monitor pressure differences in ducts and equipment. Changes in pressure can provide information about blockages, airflow conditions or equipment performance. Flow measurement can similarly help determine whether material is moving at the expected rate. When combined with level measurement, flow sensors can help maintain a balanced process.

For example:

Storage bin → controlled flow → milling → separation → conveying → finished-product bin

At each stage, sensors can provide information about what is happening.

7) Optical Sensors and Machine Vision

Not all sensors measure quantities such as temperature or moisture. Some sensors “look” at

the material. Digital cameras and machine-vision systems can analyse visible characteristics such as colour, shape, size and surface defects. Research on grain-quality sensing has demonstrated applications of RGB imaging, multispectral imaging and NIR technologies for different grain characteristics. In a modern processing plant, machine vision can potentially assist with foreign-material detection, colour classification, grain-size analysis, defect detection, product inspection, monitoring of visible contamination or specks. The development of artificial intelligence is expanding these possibilities. A conventional camera produces an image. An AI-based system can be trained to recognise patterns within those images. The combination can be represented as:

Camera → Image → Computer vision → Classification → Process decision

8) Sensors for Food Quality

The ultimate purpose of many sensors in a grain mill is not simply to protect machinery. It is to produce a consistent and acceptable food product. In flour milling, parameters such as moisture, protein and ash are important quality characteristics. Industrial NIR applications specifically describe real-time monitoring of these parameters during milling. For example, protein concentration can be important because different flour products are intended for different applications. Moisture affects storage and processing characteristics. Ash is related to mineral content and can provide information relevant to flour quality and milling performance. If these properties can be monitored rapidly, the mill can respond more quickly to variation in raw material and process conditions.

Individual Sensors to a Smart Mill

A single sensor provides one piece of information. A smart milling system combines information from many sensors. Consider a simplified mill equipped with moisture sensors, NIR quality sensors, temperature sensors, vibration sensors, level sensors, pressure sensors, flow sensors, machine-vision cameras etc. Each sensor produces data. A control system can collect these data and present them to operators through a human-machine interface (HMI) or supervisory control system. This creates a digital representation of the physical process. A simplified architecture of this process is depicted in the figure 2.

Challenges

Despite their advantages, sensors are not a magic solution. Several challenges remain.

Cost: *Advanced sensors, installation and control infrastructure can require significant investment.*

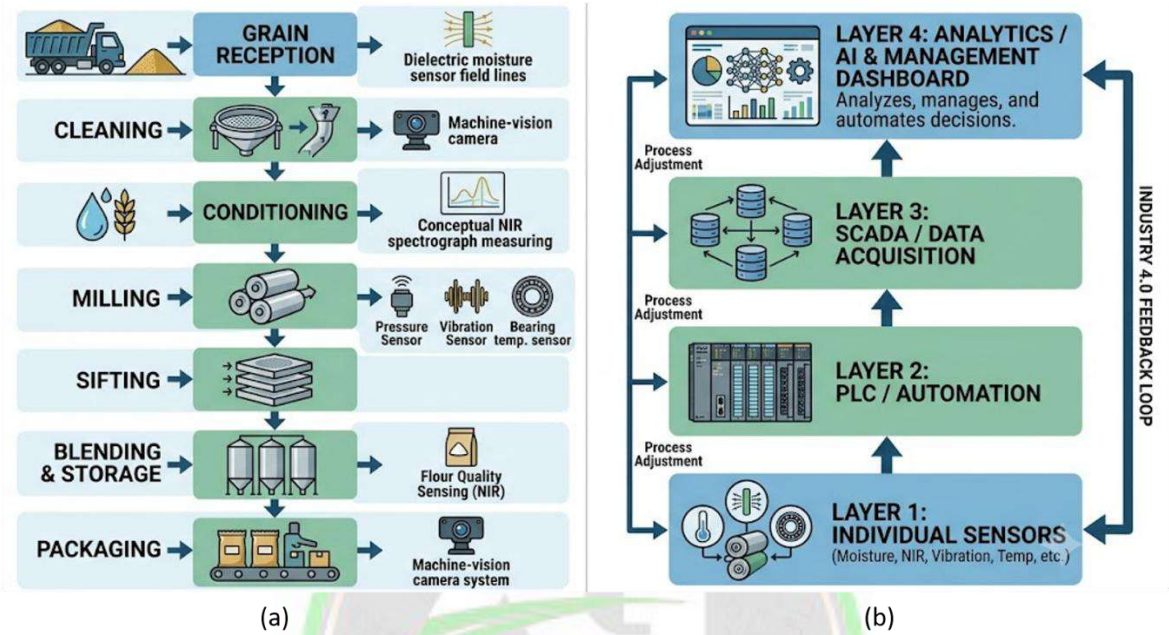


Figure 2: (a) Grain milling process and sensors equipped (b) Architecture of a smart mill

Calibration: *Sensors must be calibrated for the material and operating conditions.*

Maintenance: *Sensors themselves require inspection, cleaning and periodic verification.*

Data overload*: Collecting thousands of measurements does not automatically improve a process. Poorly designed systems can generate more information than operators can use.*

Integration*: Sensors from different manufacturers may use different communication systems and data formats.*

Skilled personnel*: A smart mill still requires people who understand grain science, milling technology, instrumentation, automation and data analysis.*

Predictive Maintenance: A new approach of sensor-based maintenance"

Traditional maintenance often follows one of two approaches i.e., run to failure which means repair equipment after it breaks and preventive maintenance which means inspect or replace components according to a fixed schedule. But sensor-based condition monitoring introduces another approach called predictive or condition-based maintenance in which maintenance decisions are made using information about actual equipment condition. Vibration and temperature sensors are particularly useful for this purpose. A historical record of sensor

measurements can establish a normal operating baseline. Deviations from that baseline can then be investigated. With sufficient data, analytical and machine-learning methods may help identify patterns associated with developing faults. The objective is not simply to collect more data. The objective is to turn data into useful maintenance decisions.

Artificial Intelligence and the Future Mill

The next stage of sensor development is closely connected with artificial intelligence. Modern mills can generate large amounts of data. Sensors can record measurements every second or even faster. Over weeks and months, this produces a substantial historical dataset. AI and machine-learning algorithms can potentially identify relationships that are difficult to detect manually. Applications may include:

- Predictive maintenance
- Product-quality prediction
- Anomaly detection
- Process optimisation
- Automated visual inspection
- Energy monitoring
- Raw-material classification

However, AI should not be viewed as a replacement for fundamental milling knowledge. The strongest systems combine domain knowledge, reliable sensors, good data and appropriate algorithms.

Automation does not eliminate the need for skilled millers. Instead, it changes their role. A traditional operator may spend considerable time observing equipment and taking samples. A modern operator can receive information from dozens or hundreds of sensors through a central interface. The miller therefore becomes increasingly a process manager and decision-maker. Experience remains essential because sensor data must be interpreted in the context of grain behaviour, machine operation and product requirements. Technology provides information. Human expertise provides meaning.

Conclusion

Sensors are quietly changing grain milling. Moisture sensors help control one of the most important properties of grain. NIR sensors can provide rapid information about moisture, protein and ash. Temperature and vibration sensors help protect machinery. Level, pressure and flow

sensors help control material movement. Cameras and machine-vision systems provide new possibilities for product inspection. When these sensors are connected through automation and data-analysis systems, a traditional milling plant can evolve into a smart milling system. The most important change is not the sensor itself. It is the shift from periodic observation to continuous information. A mill that knows what is happening can respond more quickly. A mill that records what is happening can learn from its history. And a mill that combines reliable measurements with engineering knowledge can move toward more consistent quality, better maintenance and more efficient production. The future of grain milling will therefore not be simply about grinding grain faster. It will be about seeing, measuring, understanding and controlling the process better.

References

Farahani, H., Wagiran, R., & Hamidon, M. N. (2014). *Humidity Sensors Principle, Mechanism, and Fabrication Technologies: A Comprehensive Review*. Sensors, 14, 7881–7939. MDPI

Jones, S. B., Sheng, W., & Or, D. (2022). *Dielectric Measurement of Agricultural Grain Moisture—Theory and Applications*. Sensors, 22, 2083. MDPI

New Sensing Technologies for Grain Moisture. Agriculture, 12, 386 (2022). MDPI

Technologies and Data Analytics to Manage Grain Quality On-Farm—A Review. Agronomy, 13, 1129 (2023). MDPI

BUCHI. *Monitoring the Milling Step in the Flour Industry: Determination of Moisture, Protein, and Ash in Flour*. BÜCHI

BUCHI. *Determination of Quality Parameters in Flour*. BÜCHI

Principles, Applications, and Future Evolution of Agricultural Nondestructive Testing Based on Microwaves. Sensors, 25, 4783 (2025). MDPI

Volume: 06 Issue No: 09

EMERGING CONTAMINANTS IN AQUATIC ENVIRONMENTS AND THEIR EFFECTS ON FISH

Article ID: AG-V06-I09-66

Reshmy E B [1]* and T. Varsha Chythanya[2]

[1]Department of Aquatic Environment and Management, Kerala University of Fisheries and Ocean studies, Panangad P.O, Kochi, Kerala,India.

[2]Department of Fish Pathology and Health Management,

Tamilnadu Dr.J.Jayalalitha Fisheries University, Fisheries College and Research Institute Thoothukudi, Tamil Nadu, India

*Corresponding Author: Reshmy E B

Abstract

Emerging contaminants are a diverse group of chemical and particulate substances that are increasingly detected in aquatic ecosystems and are receiving scientific attention because of their persistence, biological activity, widespread occurrence and potential ecological risks. Unlike conventional pollutants, many emerging contaminants are not routinely monitored or regulated, despite their continuous introduction into rivers, lakes, estuaries, reservoirs and marine environments. Major groups include pharmaceuticals and personal care products, endocrine-disrupting chemicals, per- and polyfluoroalkyl substances (PFASs), pesticides, antibiotics, microplastics, nano-materials, industrial chemicals and other contaminants of emerging concern. Wastewater discharge, agricultural runoff, industrial activities, aquaculture, domestic sewage, landfill leachate and urban drainage are important pathways through which these contaminants enter aquatic systems. Fish are particularly vulnerable because they are continuously exposed through water, sediments and food. Emerging contaminants can affect fish at molecular, cellular, physiological, behavioural, reproductive and population levels. Reported effects include oxidative stress, DNA damage, endocrine disruption, altered metabolism, impaired growth, reproductive abnormalities, behavioural changes, immune dysfunction and developmental toxicity. Some substances may bioaccumulate and biomagnify through aquatic food webs.

Recent reviews indicate that wastewater treatment plants are important sources of several emerging pollutants and that some contaminants may persist in treated effluents. Effective management therefore requires improved monitoring, advanced wastewater treatment, source control, ecotoxicological testing and risk-based regulation.

Keywords: Emerging contaminants, aquatic environment, fish, ecotoxicology, pharmaceuticals, PFASs, microplastics, endocrine disruptors, bioaccumulation, aquatic pollution.

1.Introduction and Concept of Emerging Contaminants

Hi Emerging contaminants, also referred to as **contaminants of emerging concern (CECs)**, represent a broad and continuously changing group of substances that are newly recognised as environmental pollutants or for which environmental occurrence and ecological effects are becoming increasingly important. The term does not necessarily mean that the chemicals themselves are newly manufactured. The 2024 review by Yu et al. identified pharmaceuticals and personal care products, PFASs, disinfection by-products, brominated flame retardants and microplastics among important groups of emerging pollutants in aquatic environments. Traditional aquatic pollutants such as petroleum hydrocarbons, pesticides, heavy metals and persistent organic pollutants have been extensively studied and are regulated in many countries.. Pharmaceuticals are an important example. They are designed to produce physiological effects in humans or animals and may retain biological activity after entering wastewater and receiving waters. Emerging contaminants include pharmaceuticals, antibiotics, hormones, steroid compounds, personal-care products, surfactants, plasticisers, flame retardants, PFASs, nanoparticles, microplastics and several industrial chemicals.Some remain dissolved in water, while others attach to suspended particles or sediments. Some are relatively persistent,

2. Major Sources and Pathways of Emerging Contaminants

The occurrence of emerging contaminants in aquatic environments is closely related to human activities. **Municipal wastewater** is one of the most important pathways because domestic sewage contains pharmaceuticals, antibiotics, hormones, personal-care products, detergents and other chemicals. Pharmaceutical residues enter wastewater after human use and excretion. Veterinary medicines can reach aquatic environments through livestock operations and aquaculture. Antibiotics may enter water through pharmaceutical manufacturing, hospitals, households, livestock farms and aquaculture facilities. Personal-care products such as fragrances, preservatives, antimicrobial agents and UV filters can also enter wastewater.**Agricultural runoff**

is another important pathway. Pesticides, veterinary pharmaceuticals, fertilisers and other chemicals may be transported from agricultural land to streams and ponds during rainfall. Intensive aquaculture can contribute antibiotics, anti-parasitic drugs, disinfectants, feed additives and other chemical residues to surrounding waters through farm effluents.**Industrial activities** may release PFASs, plasticisers, flame retardants, solvents, surfactants and other chemical substances. **Landfill leachate** can contain pharmaceuticals, plastic-related chemicals and other contaminants that may eventually enter groundwater and surface waters.**Atmospheric transport** is also relevant for certain persistent chemicals. Contaminants released into the atmosphere can undergo long-range transport and deposition into aquatic environments.A recent review found that wastewater treatment plants are important sources of emerging pollutants and that sludge and sediment can represent important environmental destinations for many compounds.

3. Pharmaceuticals and Personal Care Products

Pharmaceuticals and personal-care products (PPCPs) are among the most extensively studied emerging contaminants. They include analgesics, antibiotics, antidepressants, antihypertensive drugs, hormones, veterinary medicines, fragrances, preservatives, cosmetics and antimicrobial compounds. PPCPs enter aquatic systems primarily through domestic wastewater, hospitals, pharmaceutical industries, agricultural activities and aquaculture.when present at relatively low concentrations, some compounds can interact with physiological pathways in aquatic organisms. Fish may absorb pharmaceuticals directly through the gills and skin or indirectly through contaminated food. Once absorbed, contaminants can be transported through the bloodstream to organs such as the liver, kidney and brain. The liver plays a major role in biotransformation, while gills are important sites of direct environmental exposure.Reported effects include changes in enzyme activity, oxidative stress, altered metabolism, behavioural abnormalities, reproductive impairment and developmental effects. Antibiotics can also contribute indirectly to the development and selection of antimicrobial resistance in aquatic environments.Reviews indicate that analgesics, stimulants and several other pharmaceutical groups can occur in wastewater and treated effluents.

4. Endocrine-Disrupting Chemicals and Effects on Fish Reproduction

Endocrine-disrupting chemicals (EDCs) are substances capable of interfering with hormonal systems. They include natural and synthetic hormones, alkyl phenols, bisphenol, phthalates, certain pesticides, pharmaceuticals and industrial chemicals. Hormones regulate

processes such as growth, development, sexual maturation, gamete production and reproduction. Fish exposed to estrogenic substances may show altered production of vitellogenin, a protein normally associated with egg development. Increased vitellogenin in male fish can therefore serve as a biomarker of estrogenic exposure.EDCs can influence reproductive development in both male and female fish. Potential effects include altered gonadal development, abnormal sex differentiation, reduced sperm quality, altered egg production and changes in reproductive behaviour. Endocrine disruption can also interact with other stressors such as temperature change, hypoxia, habitat degradation and nutritional stress. Therefore, risk assessment should consider realistic environmental conditions rather than evaluating each contaminant in complete isolation.

5. PFAS and Other Persistent Emerging Chemicals

Per- and polyfluoroalkyl substances (PFASs) are a large group of fluorinated chemicals characterized by strong carbon–fluorine bonds. They have been widely used in industrial and consumer applications because of their resistance to heat, water and oil. However, their environmental persistence has created concern about long-term contamination. Depending on the compound, PFASs may accumulate in organs and tissues and can potentially move through aquatic food webs. Recent reviews identify PFASs among important emerging pollutant groups and emphasize their long-term environmental transport potential. Potential effects of PFAS exposure include oxidative stress, altered lipid metabolism, immune effects, developmental toxicity and changes in biochemical pathways. However, toxicity varies among PFAS compounds, fish species, concentrations and exposure conditions. Therefore, it is inappropriate to assume that all PFASs have identical environmental behaviour or toxicity.

6. Microplastics and Nanoplastics as Emerging Contaminants

Microplastics are small plastic particles generally less than 5 mm in size, while nanoplastics are much smaller particles within the nanoscale range. Microplastics originate from the fragmentation of larger plastic items, synthetic textiles, industrial materials, packaging, fishing gear and other sources. In fisheries, abandoned and lost fishing gear is particularly relevant because nets, ropes and other plastic materials can fragment over time.Fish can ingest microplastics directly from water or sediment or indirectly through contaminated prey. The effects of microplastics on fish can include oxidative stress, inflammation, altered enzyme activity, impaired growth and behavioural changes. Nanoplastics may be particularly important

because their small size potentially allows greater interaction with biological membranes and tissues. Management should focus on reducing plastic input at source, improving waste collection, controlling plastic discharge from industries and aquaculture, preventing loss of fishing gear and promoting environmentally responsible fishing practices.

7. Antibiotics, Antimicrobial Resistance and Aquatic Ecosystems

Antibiotics represent another important class of emerging contaminants. The widespread use of antibiotics creates concern not only because of direct toxicity but also because aquatic environments may contribute to the development and dissemination of **antimicrobial resistance (AMR)**.Aquaculture is particularly relevant because improper use can result in residues entering surrounding water through uneaten feed, fish excretion and farm effluents.Antibiotics may affect aquatic microorganisms and microbial communities. More importantly, sublethal concentrations can create selection pressure favouring resistant microorganisms. Resistance genes can potentially move between microorganisms through horizontal gene transfer. Depending on the compound, exposure may influence gut microbial communities, immune function, metabolism and physiological health. A major challenge is that conventional water-quality assessment may focus on chemical concentrations without considering biological consequences such as resistance development. Therefore, modern aquatic environmental management should combine chemical monitoring with microbiological and ecological assessments.For sustainable aquaculture, antibiotics should be used responsibly and preferably within integrated disease-management programmes.

8. Toxicological Effects of Emerging Contaminants on Fish

The effects of emerging contaminants on fish can occur at multiple biological levels. **Molecular and biochemical responses** often occur before visible effects at the organism or population level. These early responses are therefore useful as biomarkers for environmental monitoring.One important mechanism is **oxidative stress**. Exposure to certain contaminants can increase the formation of reactive oxygen species. When antioxidant defenses are insufficient, oxidative damage may occur to lipids, proteins and DNA. Enzymes such as superoxide dismutase, catalase and glutathione-related enzymes are commonly studied as indicators of oxidative stress.Emerging contaminants can also produce **genotoxic effects**. DNA strand breaks, chromosomal damage and micronucleus formation have been reported as potential responses to chemical exposure. Such endpoints are particularly relevant for aquatic environmental

toxicology because genetic damage may influence cell function and long-term organismal health. Histopathological changes in the gills, liver, kidney and gonads can provide evidence of chronic exposure.The **gills** are particularly sensitive because they provide a large surface area for exchange between fish and water. The liver is important for metabolism and detoxification and may show cellular alterations following contaminant exposure.Such effects are ecologically important because behaviour directly influences survival and reproductive success.

9. Bioaccumulation, Biomagnification and Food-Web Effects

Bioaccumulation occurs when an organism accumulates a substance from its environment and/or food at a rate greater than its ability to eliminate it. **Biomagnification** refers to increasing contaminant concentrations at higher trophic levels in a food web. Both processes are important considerations when evaluating persistent emerging contaminants.Fish may accumulate contaminants through three major pathways: direct uptake from water, ingestion of contaminated sediment and consumption of contaminated prey. The relative importance of these pathways depends on the chemical properties of the contaminant and feeding ecology of the species.Persistent and lipophilic contaminants are particularly capable of accumulating in biological tissues. However, not every emerging contaminant behaves in the same way. Some highly water-soluble pharmaceuticals may show limited tissue accumulation, whereas persistent substances such as certain PFASs or hydrophobic compounds may have greater potential for retention.Bioaccumulation has implications for fisheries because fish are important components of aquatic food webs. Predatory species may be exposed to contaminants through consumption of contaminated prey. Consequently, contaminants can potentially move through food webs.Recent review evidence indicates that some emerging pollutants have significant potential for bioaccumulation and biomagnification,

10. Monitoring, Risk Assessment and Management Strategies

Effective management of emerging contaminants requires a combination of **source control, environmental monitoring, analytical chemistry, toxicological assessment and advanced treatment technologies**. Because emerging contaminants occur at low concentrations and include many chemically diverse compounds, sensitive analytical methods are required.Monitoring programmes should include water, sediment and biological samples. Fish tissue analysis is particularly valuable because it provides information about biological exposure rather than simply environmental concentration.Modern analytical techniques such as liquid

chromatography coupled with mass spectrometry and high-resolution mass spectrometry allow simultaneous detection of multiple compounds. Non-target screening can also help identify previously unrecognized contaminants.

Risk assessment generally considers **hazard, exposure and ecological effects**. However, conventional approaches may be insufficient for mixtures because aquatic organisms are exposed to multiple contaminants simultaneously. Mixture toxicity, transformation products and chronic low-dose exposure should therefore receive greater attention.Wastewater treatment is an important management point. Conventional treatment may not completely eliminate several PPCPs and other emerging contaminants. Advanced technologies such as activated carbon adsorption, ozonation, membrane processes and advanced oxidation can improve removal for selected compounds. The appropriate technology depends on contaminant characteristics, treatment objectives and economic feasibility. Source reduction is often more sustainable than relying exclusively on end-of-pipe treatment. Responsible pharmaceutical disposal, reduced unnecessary chemical use, improved industrial management, plastic-waste reduction and better aquaculture practices can reduce contaminant inputs.Environmental regulations should also be updated as scientific evidence develops. Monitoring priorities should consider persistence, bioaccumulation potential, toxicity, occurrence, exposure and ecological importance.For India, increased monitoring of emerging contaminants is particularly important because of rapid urbanization, pharmaceutical use, industrialization, intensive agriculture and expansion of aquaculture. Recent research has highlighted gaps in monitoring across parts of Asia and other developing regions.

Conclusion

Emerging contaminants represent a complex and evolving challenge for aquatic environmental management and fisheries science. Pharmaceuticals, personal-care products, endocrine-disrupting chemicals, antibiotics, PFASs, microplastics, nanomaterials and other contaminants can enter aquatic ecosystems through wastewater, agricultural runoff, industrial discharge, aquaculture, landfill leachate and urban activities. Their environmental importance is increased by continuous release, persistence, biological activity and the limitations of conventional wastewater treatment. Fish are particularly important organisms for evaluating the effects of these contaminants because they are continuously exposed through water, sediment and food and occupy different trophic positions. Emerging contaminants can produce effects

ranging from biochemical and molecular alterations to oxidative stress, DNA damage, endocrine disruption, histopathological changes, behavioural abnormalities, impaired growth and reproductive dysfunction. Chronic and multigenerational effects are becoming increasingly important areas of research. Future aquatic environmental management should therefore emphasize regular monitoring, sensitive analytical methods, fish-based biomarkers, advanced wastewater treatment, source reduction and improved risk assessment. Particular attention should be given to contaminant mixtures and chronic low-concentration exposure rather than focusing only on acute toxicity.

References

Yu, Y., et al. (2024). Occurrence, bioaccumulation, fate, and risk assessment of emerging pollutants in aquatic environments: A review. *Science of the Total Environment, 923*, 171388. https://doi.org/10.1016/j.scitotenv.2024.171388

Wilkinson, J. L., Thornhill, I., Oldenkamp, R., Gachanja, A., & Busquets, R. (2024). Pharmaceuticals and personal care products in the aquatic environment: How can regions at risk be identified in the future? *Environmental Toxicology and Chemistry, 43*(3), 575–588. https://doi.org/10.1002/etc.5763

Fadare, O. O., et al. (2017). Pharmaceuticals and personal care products (PPCPs) in the freshwater aquatic environment. *Emerging Contaminants, 3*(1), 1–16. https://doi.org/10.1016/j.emcon.2016.12.004

aus der Beek, T., et al. (2022). Abundance, fate, and effects of pharmaceuticals and personal care products in aquatic environments. *Journal of Hazardous Materials, 424*, 127284.

Li, S., et al. (2021). Ecotoxicological effects, environmental fate and risks of pharmaceutical and personal care products in the water environment: A review. *Science of the Total Environment, 788*, 147819.

Ebele, A. J., Abou-Elwafa Abdallah, M., & Harrad, S. (2017). Pharmaceuticals and personal care products (PPCPs) in the freshwater aquatic environment. *Emerging Contaminants, 3*(1), 1–16.

Pharmaceuticals and personal care products and their sublethal and lethal effects in aquatic organisms. (2021). *Environmental Reviews, 29*(2), 142–181. https://doi.org/10.1139/er-2020-0054

Sefali, S., et al. (2026). Toxicological implications of emerging pollutants on aquatic organisms. *Discover Environment, 4*, 43.

Siddiqui, S., & Brander, S. M. (Eds.). (2024). Aquatic Ecotoxicology: Understanding Pollutants, Aquatic Organisms, and their Environments.

Volume: 06 Issue No: 09

NANOFERTILIZERS FOR SUSTAINABLE CROP PRODUCTION: CHALLENGES AND PROSPECTS

Article ID: AG-V06-I09-67

Sowmiah S

Centre for Agricultural Nanotechnology, Tamil Nadu Agricultural University,

Coimbatore – 641 003, Tamil Nadu, India

Introduction

Agricultural production depends heavily on the availability of essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), iron (Fe), zinc (Zn), manganese (Mn), copper (Cu) and boron (B). Conventional fertilizers have contributed substantially to increased agricultural productivity, but their efficiency is often limited by nutrient losses through leaching, runoff, volatilization, fixation and other processes. Low nutrient-use efficiency not only increases the amount of fertilizer required but may also contribute to environmental problems such as eutrophication, ground water contamination and green house gas emissions. These limitations have encouraged the development of alternative nutrient-delivery technologies, among which nanofertilizers have received considerable attention.

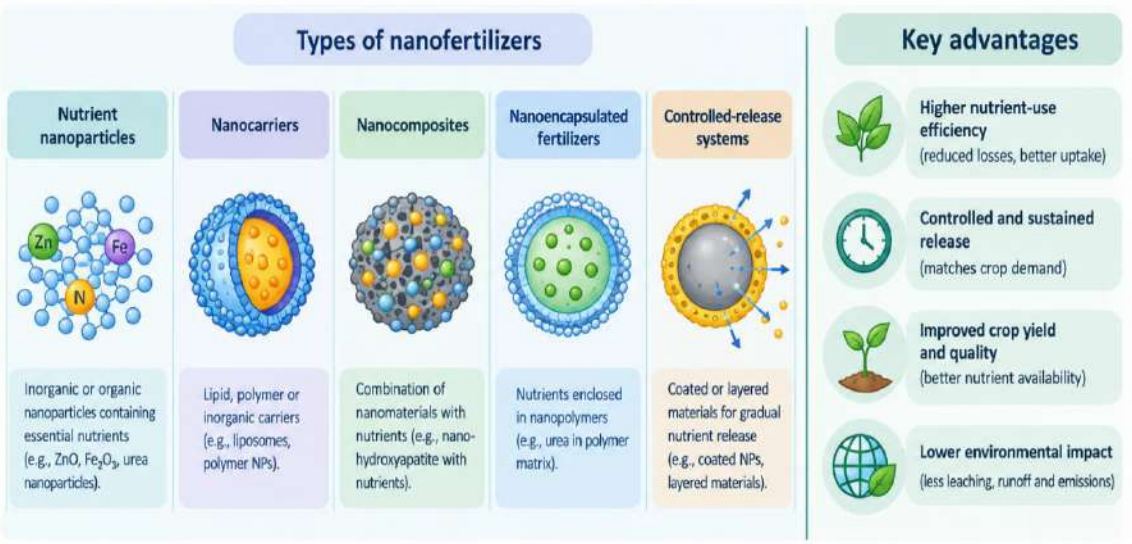


Figure 1. Types of nanofertilizers and their advantages

Nanofertilizers are broadly defined as fertilizer systems in which nutrients are supplied in nanoscale incorporated, encapsulated, adsorbed or coated onto nanostructured materials. Their development is based on the special properties of nanomaterials, including high surface area to volume ratio, enhanced surface reactivity and the possibility of controlling nutrient release rates. Depending on their formulation, nanofertilizers may function as nutrient nanoparticles, nanocarriers, nanocomposites, nanoencapsulated fertilizers or controlled-release fertilizer systems. The major attraction of nanofertilizers is their potential to improve nutrient-use efficiency by providing nutrients gradually and, in some cases, closer to the time and location of plant demand (Figure 1).

1. Soil–Nanofertilizer Interactions

After application, nanofertilizers enter a highly complex soil environment. Soil contains clay minerals, organic matter, microorganisms, water, dissolved ions and mineral surfaces that can interact with nanoparticles. Consequently, nanoparticles may undergo adsorption, desorption, aggregation, agglomeration, dissolution, precipitation, complexation and redox transformation. Soil pH is particularly important because it can influence nanoparticle surface charge, dissolution and nutrient availability. Acidic and alkaline soils may therefore produce different responses to the same nanofertilizer. Soil texture also affects nanoparticle movement. Clay-rich soils retain nanoparticles through adsorption, whereas sandy soils permit greater mobility.

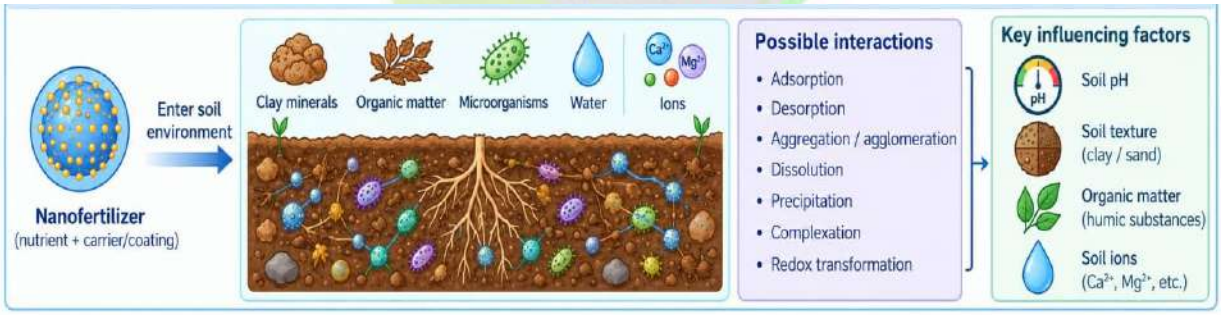


Figure 2. Soil-Nanofertilizer interactions

Soil organic matter is another important factor. Humic substances adsorb onto nanoparticle surfaces and modify their surface charge, aggregation and mobility. Depending on the type of nanoparticle and organic matter, this interaction may either increase dispersion or promote immobilization. Calcium, magnesium and other ions present in soil solution can reduce electrostatic repulsion between particles and promote aggregation. Once aggregation occurs, the

effective particle size increases and the material behave more like a conventional particulate material. These interactions make it difficult to predict nanofertilizer behaviour under field conditions. The controlled environment used in laboratory experiments cannot reproduce the complete chemical and biological complexity of agricultural soils (Figure 2).

Controlled Nutrient Release

Controlled nutrient release is one of the major reasons for developing nanofertilizers. Conventional soluble fertilizers release nutrients rapidly, whereas plants may not be able to absorb the entire quantity immediately. This mismatch between nutrient release and crop demand result in nutrient losses. Nanofertilizers potentially reduce this problem by incorporating nutrients into nanocarriers or coatings that regulate nutrient diffusion. However, controlling nutrient release under real soil conditions is challenging because release is affected by moisture, temperature, pH, microbial activity, ionic strength and root exudates (Figure 3). The researchers prepared a nanohybrid fertilizer using 6:1 urea-to-hydroxyapatite ratio by weight, with approximately 40% nitrogen by weight. The high surface area of hydroxyapatite nanoparticles enabled substantial urea loading while slowing its release. The study demonstrated the potential for maintaining crop yield with reduced urea input under the conditions tested. Similarly, urea–hydroxyapatite–montmorillonite nanohybrid composites exhibited slow nitrogen-release behaviour for up to140 days in soil and increased rice grain yield was observed in pot experiments. These studies demonstrate the potential of controlled-release systems, but laboratory and pot-scale release profiles cannot automatically be correlated to agricultural fields. The controlled-release nanofertilizers can potentially improve nutrient-use efficiency and reduce nutrient losses, but their release mechanisms, analytical detection, environmental behaviour and commercial viability require further investigation.

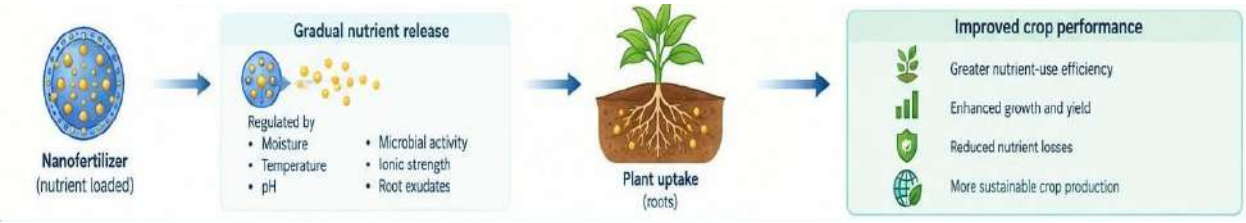


Figure 3. Controlled release mechanism of nanofertilizer

4. Plant Uptake and Nutrient Bioavailability

The interaction between nanofertilizers and plant roots is another important challenge.

After application, nutrients may become available through several pathways. Nanoparticles can dissolve and release nutrient ions, or nanoparticles themselves may interact with root surfaces and potentially enter plant tissues. They may also undergo transformation in the rhizosphere before nutrients become available. The relative contribution of these mechanisms is still not completely understood for many nanofertilizer systems. It is therefore important to distinguish between the effects of intact nanoparticles and those of dissolved ions. Plant species also differ considerably in their response. Root architecture, root exudates, cell-wall properties, membrane transport systems and nutrient requirements influence nanoparticle uptake. Consequently, a nanofertilizer developed for one crop may not show identical behaviour in another crop. Application method also influences uptake. Soil application exposes nanoparticles to soil chemistry and microorganisms, whereas foliar application exposes them directly to leaf surfaces. Seed treatment may expose germinating seeds and young roots to nanoparticles. Therefore, dose and formulation must be optimized for each application route.

5.Phytotoxicity and Oxidative Stress

Although nanofertilizers are intended to improve plant nutrition, excessive exposure may produce adverse effects. Phytotoxicity depends on nanoparticle composition, concentration, size, surface properties, exposure duration and plant species. Possible effects include inhibition of seed germination, reduced root and shoot growth, chlorosis, altered photosynthesis, nutrient imbalance, membrane damage and changes in enzyme activity. Some nanoparticles can also induce the production of reactive oxygen species (ROS). Plants naturally produce ROS as part of normal metabolic processes and signaling. However, excessive ROS production result in oxidative stress, leading to lipid peroxidation, protein oxidation and cellular damage. The antioxidant defence system of the plant determines its ability to tolerate nanoparticle exposure. Importantly, the response is often dose-dependent. A low concentration may stimulate growth or nutrient uptake, whereas a higher concentration may become toxic. Therefore, nanofertilizer recommendations should be based on dose–response studies rather than on a single concentration. The engineered nanomaterials can influence plant nutrient availability and uptake but that their biological effects depend on material characteristics and exposure conditions. The nanofertilizers should not be assumed to be universally safe because different nanomaterials can produce different biological responses.

6.Effects on Soil Microorganisms

Soil microorganisms are essential for maintaining soil fertility. Bacteria and fungi participate in nitrogen fixation, nitrification, denitrification, organic-matter decomposition, phosphorus solubilization and other nutrient-cycling processes. Nanofertilizers may interact directly with microorganisms or indirectly modify the rhizosphere through changes in nutrient availability. Some nanoparticles, particularly metal-based materials, possess antimicrobial properties and may therefore influence beneficial microbial populations. The effects of nanofertilizers on soil and plant-associated microbial communities and highlighted the need to maximize their agricultural benefits while minimizing ecological risks. Changes in microbial community composition may have consequences beyond the immediate fertilizer response. For example, disruption of beneficial microorganisms could influence nutrient cycling or plant-growth-promoting activities. Therefore, nanofertilizer evaluation should include microbial endpoints rather than considering only crop yield. Long-term studies are particularly important because a single application may produce limited effects, whereas repeated applications could lead to cumulative changes in microbial communities.

7. Environmental Fate, Mobility and Persistence

Once introduced into agricultural soils, nanoparticles may remain near the application site, become attached to soil particles, dissolve, aggregate or move through soil water. Their environmental fate determines the extent to which they can reach groundwater, surface water, plants and soil organisms. Rainfall and irrigation can increase the movement of mobile nanoparticles or released nutrient ions. Soil texture, organic matter, pH and ionic composition strongly influence this process. The environmental fate of a nanofertilizer is therefore different from that of a conventional dissolved fertilizer. Itis necessary to determine whether the material remains as a nanoparticle, dissolves into ions or undergoes transformation into another chemical form. This distinction is important for risk assessment. For example, a metal-containing nanoparticle may produce biological effects through both particle-specific mechanisms and release of metal ions. Therefore, environmental studies should include appropriate ionic controls and transformation analyses. Recent research emphasizes that understanding nanofertilizer transformation, mobility and persistence in soil is essential for predicting both nutrient efficiency and ecological risk.

8. Food Safety and Human Health Concerns

The possibility of nanofertilizer-derived materials entering edible plant tissues represents another important concern. Depending on the material and exposure conditions, nanoparticles or their dissolved and transformed products may accumulate in roots, leaves, fruits or grains. However, detecting an increase in the concentration of an element in plant tissue does not necessarily demonstrate that intact nanoparticles have been transported into the tissue. For example, increased zinc concentration may result from uptake of dissolved zinc ions rather than intact zinc oxide nanoparticles. Therefore, future studies should distinguish between total elemental concentration and the actual chemical or nanoscale form present within edible tissues. The extensive environmental and food-chain release of nanomaterials could present potential health concerns and that nanofertilizer risks must be carefully examined before widespread implementation. Long-term studies involving repeated application, crop harvesting and dietary exposure are therefore required to establish the safety of different nanofertilizer formulations.

9. Dose Optimization and Application Methods

Determining the optimum dose is a major practical challenge. Conventional fertilizer recommendations are generally based on nutrient requirement, soil fertility and expected crop yield. Nanofertilizers require additional consideration of particle concentration, nutrient loading, particle size, dissolution rate and surface properties. An insufficient dose may fail to correct nutrient deficiency, whereas an excessive dose may increase phytotoxicity or environmental exposure. The application method also influences efficacy. Soil application provides direct access to the rhizosphere but exposes the nanofertilizer to complex soil interactions. Foliar application may improve direct nutrient delivery to leaves but is influenced by leaf cuticle properties, stomatal behaviour, humidity and formulation characteristics. Seed treatment may require only small quantities but must be carefully controlled because excessive nanoparticle exposure can affect germination and seedling development. Therefore, nanofertilizer recommendations should specify not only the nutrient concentration but also crop, growth stage, application method, dose and frequency.

10. Economic and Industrial Challenges

The economic feasibility of nanofertilizers remains a significant obstacle. Nanofertilizer production may require specialized equipment, high-purity raw materials, controlled synthesis, surface modification, encapsulation, drying and advanced characterization. Production costs may

therefore be considerably higher than those of conventional fertilizers. Although lower application rates could potentially compensate for higher product costs, the economic benefit must be demonstrated under actual farming conditions. Industrial-scale production is another challenge. A nanofertilizer produced successfully at laboratory scale must maintain the same particle size, morphology, nutrient loading, release rate, purity and stability when manufactured on a much larger scale. Storage stability is also important. Nanoparticles may aggregate during prolonged storage, potentially altering their dispersion and nutrient-release properties. Therefore, shelf-life testing and appropriate packaging are necessary.

11. Lack of Long-Term Field Validation

One of the most important limitations of nanofertilizer research is the relatively small number of long-term, multi-location field experiments compared with laboratory and greenhouse studies. Laboratory experiments are useful for understanding mechanisms, while pot experiments provide controlled information on plant growth and nutrient uptake. However, agricultural fields are much more complex because they contain heterogeneous soil properties and are influenced by rainfall, irrigation, temperature, microbial activity, crop rotation and farm management. Consequently, a nanofertilizer that performs well in a greenhouse may not necessarily produce the same result in farmers' fields. Long-term field trials should evaluate crop yield, nutrient-use efficiency, soil nutrient availability, nanoparticle persistence, microbial communities, nutrient leaching, food safety and economic returns. More recent reviews continue to emphasize the need for long-term field validation and scalable production before widespread agricultural adoption.

12. Regulatory and Standardization Challenges

Regulation is essential for ensuring the safe use of nanofertilizers. Conventional fertilizer regulations generally focus on nutrient content, chemical composition and product quality. Nanofertilizers introduce additional characteristics such as particle size, surface chemistry, dissolution, environmental mobility and persistence.

A comprehensive regulatory framework should therefore address:

- Physico chemical characterization;
- Nutrient content;
- Particle-size distribution;
- Nutrient-release characteristics;
- Environmental fate;

- Phytotoxicity;
- Soil microbial effects;
- Food-chain transfer;
- Human exposure;
- Occupational safety and
- Long-term environmental effects.

India has recently strengthened the regulatory framework for nanofertilizers. India's Fertilizer Control Order was amended in December 2024 with provisions specifically addressing sampling and analysis of nanofertilizers. However, standardized international approaches remain important because differences in terminology, characterization methods and risk-assessment protocols make comparison between studies difficult.

13. Life-Cycle Sustainability

The sustainability of nanofertilizers should be assessed throughout their entire lifecycle rather than only after application. A life-cycle assessment should consider:

Raw material extraction → nanoparticle synthesis → nutrient loading → formulation → packaging → transportation → agricultural application → soil transformation → plant uptake → environmental release → disposal

A nanofertilizer may reduce nutrient losses after application but require considerable energy or chemical inputs during synthesis. Therefore, improved agronomic efficiency does not automatically guarantee a lower overall environmental footprint. Green synthesis using plant extracts, microorganisms or other biological materials may reduce dependence on certain hazardous chemicals, but biological synthesis can also introduce variability in particle properties and difficulties in large-scale standardization. Thus, the environmental advantage of a nanofertilizer should be demonstrated through a complete life-cycle assessment.

14. Major Research Gaps and Future Perspectives

Future research should focus on transforming nanofertilizers from promising experimental materials into reliable and practical agricultural products. Greater emphasis is needed on the development of standardized terminology and characterization protocols, with consistent reporting of particle size, surface properties, nutrient loading, dissolution behaviour and aggregation characteristics to facilitate meaningful comparison among studies. More soil-based and field-oriented investigations are also required to understand the behaviour of

nanofertilizers under realistic agricultural conditions. Long-term studies involving repeated applications are particularly important for determining potential nanoparticle accumulation in soil and changes in beneficial microbial communities. Future investigations should also distinguish clearly between the effects of intact nanoparticles and those arising from released nutrient ions, especially in the case of metal-based nanofertilizers. Crop-specific recommendations should be developed by considering crop species, soil type, growth stage, application method and appropriate dosage. Alongside efficacy, safe-by-design approaches should guide nanofertilizer development, with formulations designed to provide sufficient nutrient availability while minimizing unnecessary environmental persistence and potential toxicity. Such an integrated approach can support the development of nanofertilizers that are both agronomically effective and environmentally compatible.

Conclusion

Nanofertilizers represent an emerging approach for improving nutrient delivery and nutrient-use efficiency in agriculture. Their nanoscale characteristics provide opportunities for controlled nutrient release, targeted delivery and potentially reduced nutrient losses. However, successful agricultural application of nanofertilizers faces several interconnected challenges. Their behaviour is strongly influenced by particle size, surface chemistry, aggregation, dissolution and interactions with soil components. Plant uptake varies with crop species and application method, while excessive exposure may cause phytotoxicity and oxidative stress. Effects on soil microorganisms, environmental persistence, mobility and food-chain transfer also require careful evaluation. Economic and technological limitations are equally important. High production costs, difficulties in large-scale manufacturing, storage stability and lack of standardized quality-control procedures may restrict commercialization. Furthermore, the limited number of long-term field experiments makes it difficult to establish reliable recommendations for repeated agricultural use. Regulatory frameworks must therefore develop alongside the technology. Nanofertilizers require assessment not only as sources of nutrients but also as engineered nanomaterials with specific physico-chemical and environmental characteristics. Overall, the future development of nanofertilizers should follow an integrated and safety-oriented approach in which nutrient-use efficiency, crop productivity, environmental fate, soil health, food safety, economic feasibility and regulatory compliance are evaluated together. Rather than simply replacing conventional fertilizers with nanoparticles, future research should

focus on designing safe, efficient, controlled-release and environmentally compatible nutrient-delivery systems. Such an approach can help determine whether nanofertilizers can make a meaningful contribution to sustainable agriculture.

References

Adisa, I. O., Pullagurala, V. L. R., Peralta-Videa, J. R., Dimkpa, C. O., Elmer, W. H., Gardea-Torresdey, J. L., & White, J. C. (2019). Recent advances in nano-enabled fertilizers and pesticides: A critical review of mechanisms of action. Environmental Science: Nano, 6, 2002–2030. https://doi.org/10.1039/C9EN00265K

Dimkpa, C. O., & Bindraban, P. S. (2018). Nanofertilizers: New products for the industry? Journal of Agricultural and Food Chemistry, 66(26), 6462–6473. https://doi.org/10.1021/acs.jafc.7b02150

Haydar, M. S., Ghosh, D., & Roy, S. (2024). Slow and controlled release nanofertilizers as an efficient tool for sustainable agriculture: Recent understanding and concerns. Plant Nano Biology, 7, 100058. https://doi.org/10.1016/j.plana.2024.100058

Kalwani, M., Chakdar, H., Srivastava, A., Pabbi, S., & Shukla, P. (2022). Effects of nanofertilizers on soil and plant-associated microbial communities: Emerging trends and perspectives. Chemosphere, 287, 132107. https://doi.org/10.1016/j.chemosphere.2021.132107

Kottegoda, N., Sandaruwan, C., Priyadarshana, G., Siriwardhana, A., Rathnayake, U. A., Arachchige, D. M. B., Kumarasinghe, A. R., Dahanayake, D., Karunaratne, V., & Amaratunga, G. A. J. (2017). Urea-hydroxyapatite nanohybrids for slow release of nitrogen. ACS Nano, 11(2), 1214–1221. https://doi.org/10.1021/acsnano.6b07781

Kottegoda, N., et al. (2017). Urea–hydroxyapatite-montmorillonite nanohybrid composites as slow-release nitrogen compositions. Applied Clay Science, 150, 303–308. https://doi.org/10.1016/j.clay.2017.09.039

Sadiq, M. V., Gupta, D., Omji Nath, M. S., Isha, Durgude, S. A., Baurai, R., Anil, A. S., Kumar, P., Mohammed Salman, C. K., & Shah, S. (2026). Re-engineering of nanofertilizers for sustainable agriculture: Synthesis, mechanistic insights, toxicity and regulatory frontiers. Frontiers in Soil Science, 6, 1677386. https://doi.org/10.3389/fsoil.2026.1677386

Toksha, B., Sonawale, M. A., Vanarase, A., Bornare, D., Tonde, S., Hazra, C., Kundu, D.,

Satdive, A., Tayde, S., & Chatterjee, A. (2021). Nanofertilizers: A review on synthesis and impact of their use on crop yield and environment. Environmental Technology & Innovation, 24, 101986. https://doi.org/10.1016/j.eti.2021.101986

Zulfiqar, F., Navarro, M., Ashraf, M., Akram, N. A., & Munné-Bosch, S. (2019). Nanofertilizer use for sustainable agriculture: Advantages and limitations. Plant Science, 289, 110270. https://doi.org/10.1016/j.plantsci.2019.110270

Wang, Z., et al. (2026). Nano-agrochemical use in sustainable agriculture and environmental protection. Nature Reviews Earth & Environment, 7, 447–468.

Volume: 06 Issue No: 09

INDIA'S PULSE STORY: FROM AREA EXPANSION TO PRODUCTIVITY GROWTH

Article ID: AG-V06-I09-68

K J V K Sirisha[1], K V S D Pravallika[2] and K Uma Devi[3]

[1] Research Associate, CARP, Ag. Economics, RARS, Lam, ANGRAU, Guntur, India

[2] Field Supervisor, CS scheme, RARS, Lam, Guntur, India

[3] Scientist, Ag. Economics, RARS, Lam, ANGRAU, Guntur, India

*Corresponding Author: K J V K Sirisha

Introduction

In India Pulses occupies a prominent place in agriculture and food consumption. They are an important source of dietary protein and also fit well into diversified cropping systems. Bengalgram, Blackgram, Greengram and Redgram together account for about 83 per cent of India's total pulse production. Each crop having its own production centres across the country. Over the past decade India's pulse sector has undergone an important change, its production has increased much faster than the area.

A decade of change: production moves ahead of area

During 2015-16 to 2025-26 India's pulse area increased (15%) from 24.91 million hectares (Mha) to 28.65 Mha (Table 1). During the same period production increased from 16.32 million tonnes (Mt) to 27.41 Mt, an increase of 68 per cent. While yield rose from 655 kg/ha to 957 kg/ha, Which about 46 per cent.

Table 1. India's pulse sector during 2015–16 to 2025–26

	2015–16	2025–26	Change (%)	CGR (%)	CV (%)
Area (M ha)	24.91	28.65	15.00	0.27	5.32
Production (Mt)	16.32	27.41	67.90	3.11	12.92
Yield (q/ha)	6.55	9.57	46.10	2.84	10.23

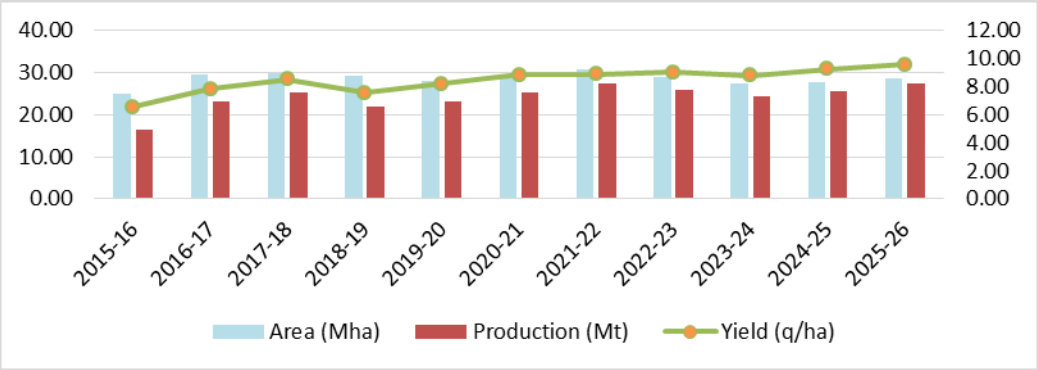


Fig.1 Production Statistics of pulses in Andhra Pradesh

The area recorded a growth rate of 0.27 per cent, compared with 3.11 per cent for production and 2.84 per cent for yield. Here production is led by yield than area. The instability index for area is low (5.32%) compared with production (12.92%) and yield (10.23%), indicates that area remained comparatively stable, while output and yield showed greater year-to-year variation.

Policy support to the pulse sector:

India's pulse sector has received sustained policy support through NFSM, MSP procurement and recently the Mission for Aatmanirbharta in Pulses. Under NFSM – pulses improved seeds, demonstrations and better crop-management technologies were promoted to raise yield and production. MSP support has also strengthened during the period, with pulse procurement at MSP rising from 1.52 lakh tonnes during 2009–14 to 82.98 lakh tonnes during 2020–25. The policy focus has now shifted towards self-sufficiency through the Mission for Aatmanirbharta in Pulses with an outlay of ₹11,440 crore for 2025–26 to 2030–31. The Mission targets 350 lakh tonnes of pulse production by 2030–31with emphasis on Tur, Urad and Masoor, climate-resilient seeds, expansion of cultivation, post-harvest infrastructure and assured MSP procurement. Thus, the policy approach has evolved from production and yield enhancement under NFSM to stronger price support and procurement and finally towards reducing import dependence and achieving self-sufficiency in pulses.

The Pulse Map of India

State-wise data for 2025–26 highlights the geographical distribution of India's major pulse crops: Bengal gram, black gram, green gram, and red gram. By examining area, production and yield together helps explain the changing spatial pattern of India's pulse production.

Bengalgram: Maharashtra and Rajasthan dominate the acreage

During 2025–26, the production was estimated at 125.14 Lt from an area of 96.60 Lha, with an average yield of 12.95 q/ha (Table 2). Maharashtra was the leading producer with 33.24 Lt (26.56%) followed by Rajasthan (19.60%) and Madhya Pradesh (16.14%). In terms of area, Maharashtra occupied the largest share (30.08%), followed by Rajasthan (21.13%) and Madhya Pradesh (12.83%). Gujarat recorded the highest yield with 18.61 q/ha, followed by Andhra Pradesh (17.36 q/ha) and Telangana (17.69 q/ha) these are substantially above the national average of 12.95 q/ha. In contrast, Karnataka recorded the lowest yield at 6.29 q/ha. Overall, Maharashtra, Rajasthan and Madhya Pradesh dominated Bengalgram production by virtue of their larger cultivated area, while Gujarat, Telangana and Andhra Pradesh exhibited relatively higher yield.

Table 2. Major Bengalgram Producing States during 2025-26

(Area - Lha, Production - Lt, Yield - q/ha)

State	Area	Share (%) in India	Production	Share (%) in India	Yield
Maharashtra	29.06	30.08	33.24	26.56	11.44
Rajasthan	20.41	21.13	24.53	19.60	12.02
Madhya Pradesh	12.39	12.83	20.2	16.14	16.30
Gujarat	9.19	9.51	17.11	13.67	18.61
Uttar Pradesh	6.9	7.14	9.44	7.54	13.68
Karnataka	6.29	6.51	3.96	3.16	6.29
Andhra Pradesh	4.11	4.25	7.13	5.70	17.36
Jharkhand	2.69	2.78	3.19	2.55	11.86
Chhattisgarh	2.5	2.59	2.46	1.97	9.86
Telangana	0.85	0.88	1.5	1.20	17.69
All India	**96.60**		**125.14**		**12.95**

Source: UPAG (3rd advance estimates)

Note: States have been arranged in descending order of percentage share of area

Blackgram: Andhra Pradesh stands out on Yield

During 2025–26, Blackgram area was 31.70 Lha, production was 21.60 Lt with an average yield of 681 q/ha (Table 3). Madya Pradesh has the major share in both area (16.72%)

and production (20.60%). while, Andhra Pradesh has the significant share (19.86%) in production with 11.69 q/ha, which was 70.66 per cent more than the national average (6.81 q/ha).

Table 3. Major Blackgram Producing States during 2025-26

(Area - Lha, Production - Lt, Yield - q/ha)

State	Area	Share (%) in India	Production	Share (%) in India	Yield
Madhya Pradesh	5.3	16.72	4.45	20.6	8.40
Andhra Pradesh	3.67	11.58	4.29	19.86	11.69
Uttar Pradesh	5.27	16.62	3.29	15.23	6.25
Maharashtra	3.8	11.99	2.39	11.06	6.30
Tamil Nadu	3.01	9.5	1.75	8.1	5.81
Rajasthan	3.79	11.96	0.92	4.26	2.42
Gujarat	1.31	4.13	0.9	4.17	6.86
All India	**31.7**		**21.6**		**6.81**

Source: UPAG (3rd advance estimates)

Note: States have been arranged in descending order of percentage share of production

Greengram: Rajasthan leads area, Madhya Pradesh leads production

In India during 2025–26, Greengram area was 61.76 Lha, production was 44.92 Lt with an average yield of 7.27 q/ha (Table 4). Among the states Rajasthan had the largest area with 26.57 L ha (43.02%) followed by Madhya Pradesh (14.74 Lha; 23.87%) and Karnataka (4.71 Lha; 7.63%). In production, Madhya Pradesh ranked first with 18.39 Lt (40.94%) followed by Rajasthan (13.89 Lt; 30.92%), Uttar Pradesh (2.18 Lt; 4.85%) and Karnataka (2.15 Lt; 4.79%). The highest yield was recorded in Madhya Pradesh (12.48 q/ha) substantially higher than the national average of 7.27 q/ha, while, Odisha recorded the lowest yield (4.20 q/ha). This scenario highlights the importance of yield alongside area expansion.

Table 4. Major Greengram Producing States during 2025-26

(Area - Lha, Production - Lt, Yield - q/ha)

State	Area	Share (%) in India	Production	Share (%) in India	Yield
Rajasthan	26.57	43.02	13.89	30.92	5.23

Madhya Pradesh	14.74	23.87	18.39	40.94	12.48
Karnataka	4.71	7.63	2.15	4.79	4.56
Odisha	3.44	5.57	1.44	3.21	4.20
Uttar Pradesh	2.65	4.29	2.18	4.85	8.21
Andhra Pradesh	0.93	1.51	0.91	2.03	9.80
All India	**61.76**		**44.92**		**7.27**

Source: UPAG (3rd advance estimates)

Note: States have been arranged in descending order of percentage share of area

Redgram: Karnataka leads area, Maharashtra leads production

During 2025–26, area was 44.6 L ha, production was 35.92 Lt with an average yield of 8.05 q/ha (Table 5). Karnataka has the major share (34%) in area with 15.21 Lha, while, Maharashtra has the major share (33%) in production with 11.78 Lt. Gujarat records the highest yield at 11.19 q/ha, followed by Uttar Pradesh (10.85 q/ha) and Maharashtra (9.61 q/ha). Andhra Pradesh recorded a yield 6.47 q/ha, which was 19.6 per cent lower than the national average (8.05 q/ha). This yield gap indicates considerable scope to enhance production, without strain on area expansion, through the adoption of improved varieties and quality seed, timely sowing, balanced nutrient management, and effective pest and disease management.

Table 5. Major Redgram Producing States during 2025-26

(Area - Lha, Production - Lt, Yield - q/ha)

State	Area	Share (%) in India	Production	Share (%) in India	Yield
Karnataka	15.21	34	7.45	21	4.90
Maharashtra	12.26	28	11.78	33	9.61
Andhra Pradesh	4.34	10	2.81	8	6.47
Gujarat	3.10	7	3.47	10	11.19
Uttar Pradesh	2.46	6	2.67	8	10.85
All India	**44.60**		**35.92**		**8.05**

Source: UPAG (3rd advance estimates)

Note: States have been arranged in descending order of percentage share of area

Overall, India's pulse production system is geographically diversified, but each pulse has its own production centres. Maharashtra is prominent in Bengalgram and Redgram. Rajasthan dominates Bengalgram and Greengram acreage. Madya Pradesh has a strong presence in Bengalgram, Blackgram and Greengram. Karnataka is a major Redgram and Greengram producing state. Andhra Pradesh has a particularly important position in Blackgram and also contributes to Redgram and Greengram.

Conclusion

India’s pulse sector has recorded a substantial increase in production over the past decade, driven primarily by improvements in yield rather than by large expansion in cultivated area. The 2025–26 state-wise picture further shows that pulse production is geographically diverse, with different states emerging as major contributors to different crops. The comparison of area, production and yield also highlights that higher production is not determined by cultivated area alone, but by how efficiently land is converted into output. Continued improvements in yield, supported by improved varieties, quality seed, better crop management, effective pest and disease management, and assured price and procurement support, will therefore remain important for strengthening India’s pulse production and reducing dependence on imports.

Volume: 06 Issue No: 09

SINGLE-CELL PROTEIN: COMPREHENSIVE REVIEW

Article ID: AG-V06-I09-69

Annapoorani S

M.Sc. Scholar, Department of Agricultural Microbiology, College of Agriculture, KAU, Vellayani, Kerala, India

Introduction

The global food system is encountering unprecedented challenges due to a combination of increasing population, limited arable land, climate change, soil degradation, freshwater scarcity, and rising demand for high-quality protein. Traditional protein sources such as livestock, poultry, and fisheries are resource intensive and environmentally burdensome. In response, alternative protein systems have gained significant interest, with single-cell protein (SCP) emerging as a leading candidate due to its rapid production cycles, minimal land usage, and potential for integration with waste recycling. SCP production is independent of climatic variability, allowing continuous biomass generation under bioreactor-controlled conditions. The integration of biotechnology, metabolic engineering, and advanced fermentation strategies has further enhanced SCP feasibility. This review synthesizes scientific and industrial knowledge on SCP.

Historical Development

The origins of SCP date back to the early 20th century, when yeast biomass was cultivated to address food shortages in Europe. The first large-scale SCP process, known as the Zulaufverfahren method, was implemented in Germany using *Saccharomyces cerevisiae* grown on molasses. By World War II, SCP production expanded significantly in Russia, where over 80 production facilities operated using *Candida utilis* and *Candida arborea*. In the 1970s, petroleum and methanol-based SCP production gained traction, particularly with Imperial Chemical Industries' (ICI) Pruteen® project using *Methylophilus methylotrophus*. Although economic factors limited hydrocarbon-based SCP commercialization, these innovations laid the foundation for modern SCP industries. Today, the SCP sector has evolved into a highly advanced

biotechnology field utilizing methane-fed fermenters, CO_2-fixation systems, and renewable-powered photobioreactors.

Characteristics of SCP Microorganisms

Ideal SCP-producing microorganisms must exhibit several critical characteristics: non-pathogenicity and absence of toxigenic metabolites; high protein yield (40–80% dry weight); balanced amino acid profile; rapid growth rate; ability to utilize low-cost substrates; environmental resilience; genetic stability; and digestible cell wall structure. Low nucleic acid content is especially important for human consumption to avoid uric acid accumulation. Microorganisms with flexible metabolic pathways and tolerance to fluctuating fermentation conditions are preferred for industrial-scale production.

Microorganisms Utilized

A diverse range of microorganisms has been explored for SCP production due to their rapid growth, metabolic versatility, and high protein content.

Algae: Microalgae such as *Chlorella*, *Scenedesmus*, and *Spirulina* are commonly cultivated in open ponds, raceways, or photobioreactors. These organisms utilize carbon dioxide and sunlight as primary inputs, making them highly sustainable for large-scale biomass production. However, large-scale algal SCP production is often constrained by the requirement for optimal illumination, which limits productivity in dense cultures or during low-light conditions. Algal biomass typically contains approximately 60% crude protein with a generally favorable amino acid profile, although sulphur-containing amino acids are present in lower proportions.

Algal SCP serves as an excellent protein-rich supplement in animal feed. Nevertheless, several drawbacks restrict its use in human nutrition. These include the high chlorophyll content, which imparts undesirable color and taste; potential gastrointestinal issues when *Chlorella* and *Scenedesmus* are consumed; comparatively low biomass density in cultures (1–2 g/L); significant contamination risks in open pond systems; and high recovery costs for unicellular algae. An exception is *Spirulina*, which can be easily harvested through filtration or skimming and is more suitable for human consumption.

Filamentous Fungi: Filamentous fungi have been widely utilized in SCP production, particularly when grown on polysaccharide-rich substrates such as starch hydrolysates and sulphite waste liquors from the wood pulp industry. In submerged fermentation, these fungi may grow in filamentous mats, yeast-like unicellular forms, or compact pellets. Their biomass

typically contains 50–55% crude protein. Although the concentration of sulphur-containing amino acids is relatively low, the overall amino acid composition is nutritionally robust. The recovery of fungal biomass is comparatively simple, especially when cells form pellets or dense mycelial aggregates suitable for filtration. However, several limitations exist. Filamentous fungi exhibit slower growth rates compared to bacteria and yeasts, though certain microfungi may approach yeast-level productivity. Contamination by fermentative yeasts is common when sterile conditions are not strictly maintained, while bacterial contamination can be minimized by maintaining the fermentation broth below pH 5. The nucleic acid content may reach up to 15% RNA, necessitating reduction treatments for human applications. Additionally, fungal strains must be rigorously screened for mycotoxin production. A proportion of nitrogen may also be present in chitin, reducing the utilizable protein fraction.

Yeasts: Yeasts belonging to *Saccharomyces*, *Candida*, and *Torulopsis* have been extensively investigated for SCP production, with *Saccharomyces* and *Candida* species widely used in industrial processes. Yeast-derived SCP typically contains 55–60% crude protein with an amino acid profile comparable to conventional plant proteins, apart from reduced levels of sulphur-containing amino acids. Yeast biomass is particularly rich in B-group vitamins, making it nutritionally valuable for both human consumption and animal feed supplementation. Yeast cultivation offers several advantages, including relatively low susceptibility to bacterial contamination and efficient biomass recovery through continuous centrifugation. However, yeasts exhibit slower growth rates than many bacteria, and similar to filamentous fungi, their nucleic acid content (up to 15%) must be reduced before human use. Methionine supplementation is often recommended to correct the deficiency of sulphur-containing amino acids in yeast proteins.

Bacteria: A wide range of bacterial species has been explored for SCP production due to their extremely fast growth rates and efficient substrate utilization. Many bacteria are capable of metabolizing diverse feedstocks, including methane, methanol, ethanol, hydrocarbons, agricultural residues, and industrial effluents. One of the most commercially successful examples is *Methylophilus methylotrophus*, used for methanol-based SCP production. Bacterial SCP typically contains more than 80% crude protein with an excellent amino acid profile, although minor deficiencies in sulphur-containing amino acids may occur in some species. Despite these advantages, bacterial SCP presents several challenges. The nucleic acid content—especially

RNA—is particularly high and must be significantly reduced for human food applications. Sterile conditions must be rigorously maintained because bacterial cultures are generally maintained at pH 5–7, a range favorable for contamination by other microbes. There is a considerable risk of pathogenic contamination, especially when gram-negative bacteria are used, necessitating careful strain selection and monitoring. Biomass recovery is more difficult due to the small size of bacterial cells. Furthermore, gram-negative bacteria may produce endotoxins, requiring stringent evaluation before their biomass can be considered safe for human consumption.

Production Process

The SCP production process consists of upstream, fermentation, and downstream operations.

Upstream Processing: Involves substrate selection and pretreatment. Common substrates include molasses, whey, lignocellulosic hydrolysates, methane, methanol, ethanol, and CO_2. Pretreatment removes toxins, balances nutrients, and sterilizes feedstock. Inoculum development ensures high-density microbial cultures for fermentation. **Fermentation:** Conducted in aerated bioreactors with controlled temperature, pH, and dissolved oxygen. Fed-batch fermentation is commonly used due to its high productivity and prevention of substrate inhibition. Oxygen transfer efficiency is critical for aerobic microorganisms. **Downstream Processing:** Includes biomass harvest via centrifugation, filtration, or flocculation; cell washing; nucleic acid reduction via heat or chemical treatment; drying via spray drying, freeze drying, or drum drying; and final formulation. Product quality depends on digestibility, safety, and nutrient retention.



Removal of Nucleic acid content and cell wall of SCP

The production of single cell protein from bacteria for human consumption requires, reducing the nucleic acid content of the cell and removal of the cell wall. The reason for reducing

nucleic acid content is because high content of the nucleic acid can lead to formation of uric acid which causes gout whereas the cell wall has very poor digestibility in humans.

Dry Material %	Bacteria	Yeast	Algae	Filamentous fungi
Protein	72 - 85	55 - 60	40 - 60	50 – 55
Fat	1.5 - 3	2 - 6	7 - 20	2 – 8
Ash	3 - 7	5 – 9.5	8 - 20	4 – 19
Free Amino Acid	8 - 12	6 - 12	3 - 8	7 – 10

Average Different Composition of Main Group of Microorganisms (Yu Pin Li et.al, 2025)

✓ **Nucleic acid removal in SCP**

This involves both the use of chemicals; such as alcohol, acid, alkali, and enzymatic methods which includes the use of nucleases and endogenous ribonucleases which hydrolyses the ribonucleic acid and reduces nucleic acid levels.

✓ **Removal of cell wall**

Mechanical and non mechanical methods are used in removal of the cell wall. The mechanical methods involves the wet milling, sonification, high pressure homogenization, decomposition crushing and grinding, while non mechanical methods are the use of chemical treatment using acid, base or detergents. Enzymatic methods such as autolysis and physical treatment such as freeze-thaw, heating and drying are used.

Nutritional Value

SCP is rich in protein (40–80% dry weight) and contains essential amino acids such as lysine, methionine, threonine, and valine. Many SCP sources also contain vitamins (B-complex), minerals (iron, zinc, magnesium), essential fatty acids (especially in algae), pigments (chlorophyll, carotenoids), and bioactive compounds. SCP protein quality is comparable to or

higher than traditional plant proteins like soy. However, digestibility depends on cell wall structure and processing methods.

Applications

SCP has global applications in human food, animal feed, and industrial sectors. In human nutrition, SCP is used for protein supplements, fortified foods, meat analogues (e.g., fungal mycoprotein), and therapeutic nutrition programs. In livestock and aquaculture, SCP replaces expensive feed proteins such as fishmeal and soybean meal. Industrial applications include enzyme production, organic fertilizers, bioremediation, and integrated biorefineries. SCP is also explored in pharmaceuticals and bioplastic development due to its functional biomolecules.

Advantages

SCP production offers numerous advantages: rapid microbial growth, independence from climatic changes, minimal land and water requirements, utilization of waste substrates, high protein density, pollution reduction, and alignment with circular bioeconomy principles. SCP production can be achieved year-round and scaled efficiently, making it economically and environmentally sustainable.

Disadvantages

Major limitations of SCP include high nucleic acid content, risk of undesirable metabolites, sensory challenges, digestibility issues in algae and fungi, high cost of processing, and consumer hesitation regarding microbial food sources. Regulatory approval can also be time-consuming depending on microorganism type and substrate used.

Future Prospects

Future developments in SCP biotechnology include CO_2-to-protein electrosynthesis, precision fermentation, CRISPR-based strain engineering, renewable energy powered bioreactors, methane-to-protein conversion, and integration with waste-to-value biorefineries. The global SCP market is projected to reach 2.5 million tonnes by 2030. Increasing demand for sustainable proteins and climate-resilient food systems positions SCP as a cornerstone of future food security.

Conclusion

Single-cell protein has emerged as a scientifically validated, environmentally sustainable and economically promising alternative to conventional protein sources. Its production is efficient, scalable and compatible with waste valorization and carbon recycling, making it an

ideal component of future food and feed systems. Although challenges related to nucleic acid content, processing costs and consumer acceptance persist, ongoing advancements in microbial biotechnology, fermentation engineering and synthetic biology hold strong potential to address these constraints. With appropriate regulatory frameworks, technological refinement and industry–academia collaboration, SCP can contribute significantly to global food security and sustainable protein production.

References

Abdur Raziq, Muhammad Lateef, Asad Ullah, Hayat Ullah and Muhammad Waseem Khan. (2020).Single cell protein (SCP) production and potential substrates: A comprehensive review. Pure and Applied Biology. Vol. 9, Issue 3, pp1743-1754. http://dx.doi.org/10.19045/bspab.2020.90185

Bratosin, B. C., Darjan, S., & Vodnar, D. C. (2021). Single Cell Protein: A Potential Substitute in Human and Animal Nutrition. Sustainability, 13(16), 9284. https://doi.org/10.3390/su13169284

Graham, A.E., Ledesma-Amaro, R. The microbial food revolution. Nat Commun 14, 2231 (2023). https://doi.org/10.1038/s41467-023-37891-1

Li, Y. P., Ahmadi, F., Kariman, K., & Lackner, M. (2024). Recent advances and challenges in single cell protein (SCP) technologies for food and feed production. NPJ science of food, 8(1), 66. https://doi.org/10.1038/s41538-024-00299-2

Silvio Jackson Felix Alves et.al,Single-cell proteins as alternative sources of proteins and nutrients,Food Research International,Volume 214,2025,116631, ISSN 0963-9969, https://doi.org/10.1016/j.foodres.2025.116631

Ugbogu, Ositadinma. (2016). A REVIEW OF MICROBIAL PROTEIN PRODUCTION: PROSPECTS AND CHALLENGES. FUW Trends in Science and Technology Journal. 1. 20485170-182.

Volume: 06 Issue No: 09

FROM THIRST TO SURVIVAL: HOW PLANTS SENSE, SIGNAL AND RESPOND TO DROUGHT

Article ID: AG-VO6-I09-70

[1]Kolli. Divya and [2]E. Revanth Kumar Goud

[1 & 2] M.Sc (Genetics and Plant Breeding), School of Agriculture,

Kaveri University, Gowraram (V), Wargal (M), Siddipet Dist., Telangana-502279, India.

*Corresponding Author: Kolli Divya

Abstract

Drought is one of the major environmental stresses affecting plant growth and crop productivity. When water availability decreases, plants cannot escape the stress and must rapidly adjust their physiology and metabolism. Drought causes changes in cellular water status, turgor, osmotic balance and membrane properties, which initiate interconnected signaling pathways involving Calcium ions (Ca^{2+}), Reactive Oxygen Species (ROS) and the hormone Abscisic acid (ABA). These signals regulate protein kinases, transcription factors and stress-responsive genes. Stomatal closure reduces water loss, while osmotic adjustment, antioxidant defense and protective proteins help maintain cellular stability. Hormonal interactions further regulate plant growth and adaptation. This article describes how plants sense drought, transmit the stress signal and activate molecular and physiological responses that determine survival, growth and ultimately crop yield.

Keywords: Drought stress, ABA, calcium signaling, ROS, stomatal closure, transcription factors, *CKX*, drought tolerance

1. Introduction

Water is essential for photosynthesis, nutrient transport, cell expansion and normal plant development. When water availability becomes insufficient, plants experience **drought stress**. At the plant level, drought occurs when water loss or demand exceeds the ability of the root–soil system to supply water.

Drought is a major constraint to agriculture because it can reduce plant growth, reproductive success and yield. Its effects are particularly severe when stress occurs during flowering and grain filling stages. Plants, however, have sophisticated mechanisms for sensing water deficit and adjusting their physiology.

The drought response involves a series of interconnected events. Changes in water status activate signaling molecules such as **Ca^{2+} ions, ROS and ABA**, which regulate ion channels, protein kinases and transcription factors. These signals eventually modify gene expression, metabolism, growth and development. Understanding this process is important for identifying mechanisms and genes associated with drought adaptation.

2. How Do Plants Sense Drought?

As soil dries, roots have increasing difficulty absorbing water. Plant water potential decreases, cells lose water and turgor pressure declines. These physical changes alter cellular and membrane properties and initiate stress signaling.

Plants do not have a single receptor specifically dedicated to detecting drought. Instead, they sense changes in hydration, osmotic conditions, turgor and hydraulic status. These changes activate several early signals, particularly **Ca^{2+}, ROS and ABA**.

Calcium signaling

Ca^{2+} acts as an important second messenger in plant stress responses. Drought and osmotic stress can activate Ca^{2+}-permeable channels such as **OSCA** (Osmolality-Sensitive Calcium Channels), **CNGC** (Cyclic Nucleotide-Gated Channels), **GLR** (Glutamate Receptor-Like Channels) and **TPC1** (Two-Pore Channel 1), resulting in changes in cytosolic Ca^{2+}. Plants decode these Ca^{2+} signals through proteins such as **calmodulins (CaM), calmodulin-like proteins (CML), calcium-dependent protein kinases (CPKs/CDPKs)** and **CBL (**Calcineurin B-like protein**)–CIPK (**CBL-interacting protein kinase**) complexes**. These proteins regulate downstream processes including ion transport, gene expression and stress responses.

Thus, calcium provides an important connection between the initial perception of drought and the plant's later responses.

3. ABA and Stomatal Closure

A major hormonal response to drought is increased production of **Abscisic acid (ABA)**. The enzyme **NCED** plays an important role in ABA biosynthesis during water deficit.

ABA is perceived by **PYR/PYL/RCAR receptors**. These receptors inhibit **PP2C phosphatases**, allowing **SnRK2 protein kinases**, including **SnRK2.2, SnRK2.3 and SnRK2.6/OST1**, to become active.

One of the fastest consequences of ABA signaling is **stomatal closure**. Activated signaling regulates ion channels such as **SLAC1** (Slow Anion Channel-Associated 1) in guard cells. Ion movement causes water to leave guard cells, reducing their turgor and closing the stomatal pore.

Stomatal closure reduces transpiration and conserves water. However, it also restricts CO_2 entry into leaves and can therefore reduce photosynthesis. Plants must consequently balance water conservation with carbon fixation.

4. Reactive Oxygen Species and Stress Signaling

Drought can increase the production of **reactive oxygen species (ROS)**, including superoxide and hydrogen peroxide. Important sources include chloroplasts, mitochondria and plasma-membrane NADPH oxidases such as **RBOHD** (Respiratory Burst Oxidase Homolog D) **and RBOHF** (Respiratory Burst Oxidase Homolog F).

ROS have two roles. At controlled concentrations they act as signaling molecules, but excessive ROS cause oxidative damage to membranes, proteins, DNA and photosynthetic machinery.

Plants control ROS through antioxidant systems. **Superoxide dismutase (SOD)** converts superoxide into hydrogen peroxide, while **catalase (CAT)** and **ascorbate peroxidase (APX)** help remove hydrogen peroxide.

ROS also interact with Ca^{2+} and ABA signaling. This interaction allows plants to integrate several stress signals and coordinate their responses.

5. From Signaling to Stress-Responsive Genes

The signals generated by ABA, Ca^{2+} and ROS eventually affect gene expression. Several transcription factor families participate in drought responses, including **DREB, NAC, WRKY, MYB and bZIP/AREB/ABF**.

ABA-dependent signaling activates AREB/ABF transcription factors through SnRK2 kinases. These transcription factors regulate genes containing ABA-responsive elements. DREB proteins are important components of ABA-independent osmotic stress responses.

The activated genes participate in processes such as osmotic adjustment, antioxidant defense, cellular protection and metabolic regulation. In this way, short-term stress signals are converted into longer-lasting changes in plant function.

6. Integrated Drought Response

The major events described above are closely interconnected rather than independent pathways. Water deficit first changes plant water status and activates Ca^{2+}, ROS and ABA signaling. These signals are decoded by calcium sensors, protein kinases and ABA signaling components. The resulting signals regulate transcription factors and stress-responsive genes.

The plant then activates several protective mechanisms, including stomatal regulation, osmotic adjustment, antioxidant defense and production of protective proteins. Hormonal crosstalk simultaneously modifies growth and development.

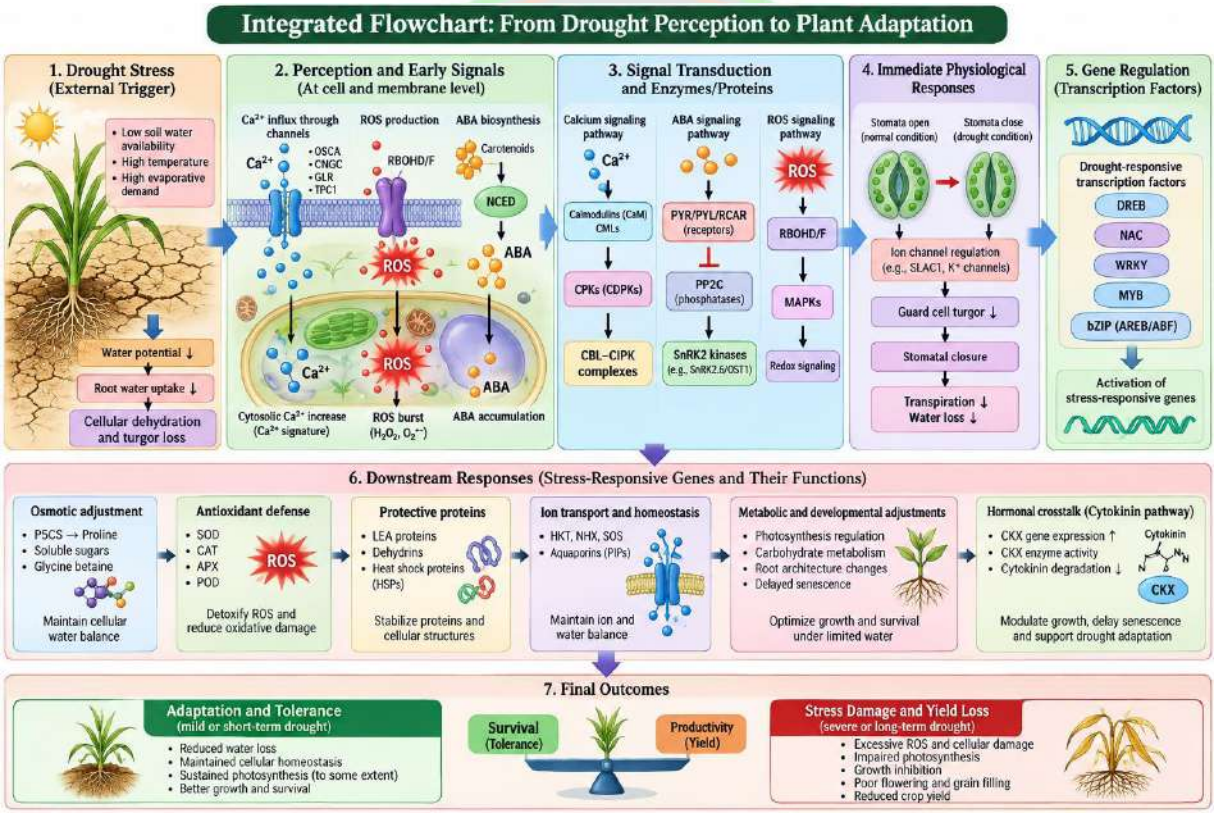


Figure 1. Integrated molecular and physiological responses of plants to drought stress, showing drought perception, Ca^{2+}, ROS and ABA signaling, stomatal regulation, transcriptional responses, osmotic adjustment, antioxidant defense, protective proteins and hormonal crosstalk. Source: Prepared by the Kolli. Divya[1] based on published literature; AI assistance was used for figure preparation.

7. How Plants Protect Their Cells

Drought causes cellular dehydration, so plants accumulate compounds known as **osmoprotectants**. Important examples include **proline, soluble sugars and glycine betaine**. These compounds help maintain osmotic balance and protect cellular structures.

Proline accumulation is particularly associated with drought responses. **P5CS** is an important enzyme involved in proline biosynthesis.

Plants also produce protective proteins such as **LEA proteins (**Late Embryogenesis Abundant**), dehydrins and heat shock proteins (HSPs)**. These proteins help stabilize cellular structures and protect proteins during dehydration.

Together, osmoprotectants, antioxidant enzymes and protective proteins help plants maintain cellular stability under water deficit.

8. Hormonal Crosstalk and Cytokinin oxidase/dehydrogenase (*CKX*)

ABA is central to drought responses, but it functions together with other hormones including **cytokinins, auxins, ethylene, jasmonates, salicylic acid and gibberellins**.

This hormonal crosstalk helps plants balance growth and survival. During severe drought, plants generally reduce growth and redirect resources toward stress protection.

Cytokinin oxidase/dehydrogenase (*CKX*) is an enzyme involved in the irreversible degradation of certain cytokinins. CKX therefore contributes to cytokinin homeostasis and can influence plant growth and development.

***CKX* is not a primary drought sensor**. Instead, its expression and activity can be influenced as part of the broader hormonal response to stress. Studying *CKX* genes can therefore help researchers understand how cytokinin metabolism is associated with drought responses.

9. From Molecular Response to Visible Symptoms

The molecular changes occurring inside drought-stressed plants eventually produce visible symptoms.

Early responses include **stomatal closure, reduced transpiration and changes in photosynthesis**. Continued water deficit can cause **reduced leaf expansion, leaf rolling, wilting, reduced plant height and reduced biomass**.

Severe or prolonged drought may cause **chlorosis, premature senescence and oxidative damage**. Reproductive stages are particularly sensitive. Drought during flowering can affect

pollen development and fertilization, while stress during grain filling can reduce grain development.

Consequently, drought can result in reduced biomass, poor reproductive development, lower grain weight and reduced final yield.

10. Why Understanding Drought Responses Matters

Drought tolerance is a complex trait controlled by interactions among water relations, signaling molecules, hormones, genes and physiological processes.

Understanding these mechanisms helps researchers identify candidate genes associated with drought responses. However, a gene that becomes more highly expressed during drought is not automatically a gene that causes drought tolerance. Its expression may simply represent part of the plant's response to stress.

Therefore, stronger evidence can be obtained by combining **gene expression data with physiological and phenotypic measurements** across contrasting genotypes.

This is particularly relevant to *CKX* genes. Comparing *CKX* expression between drought-tolerant and drought-sensitive foxtail millet genotypes may identify *CKX* members whose expression consistently changes along with contrasting drought phenotypes. Such genes can then be considered candidates for further functional validation.

Conclusion

Drought begins with reduced water availability but rapidly develops into a complex molecular response. Changes in plant water status activate interconnected Ca^{2+}, ROS and ABA signaling pathways, which regulate protein kinases, transcription factors and stress-responsive genes.The resulting responses include stomatal closure, osmotic adjustment, antioxidant defense, protective protein production and changes in growth and development. Hormonal crosstalk, including cytokinin metabolism and *CKX* activity, further contributes to the balance between growth and stress adaptation.

The visible symptoms of drought—wilting, leaf rolling, reduced growth, senescence and yield loss—are therefore the final outcomes of numerous molecular and physiological processes.Understanding this journey from water shortage to perception, signaling, gene regulation and adaptation provides a foundation for identifying drought-responsive genes and developing crops better suited to water-limited environments.

References

Boudsocq, M., & Sheen, J. (2013). CDPKs in immune and stress signaling. *Trends in Plant Science, 18*(1), 30–40.

Edel, K. H., & Kudla, J. (2016). Integration of calcium and ABA signaling. *Current Opinion in Plant Biology, 33*, 83–91.

Kudla, J., Batistič, O., & Hashimoto, K. (2010). Calcium signals: The lead currency of plant information processing. *The Plant Cell, 22*(3), 541–563.

Osakabe, Y., Yamaguchi-Shinozaki, K., Shinozaki, K., & Tran, L.-S. P. (2014). ABA control of plant growth and stress responses. *Science, 345*, 1065–1072.

Sharma, A., Prakash, S., & Chattopadhyay, D. (2022). Killing two birds with a single stone—Genetic manipulation of cytokinin oxidase/dehydrogenase (*CKX*) genes for enhancing crop productivity and amelioration of drought stress response. *Frontiers in Genetics, 13*, 941595.

Umezawa, T., Nakashima, K., Miyakawa, T., Kuromori, T., Tanokura, M., Shinozaki, K., & Yamaguchi-Shinozaki, K. (2010). Molecular basis of the core regulatory network in ABA responses: Sensing, signaling and transport. *Plant and Cell Physiology, 51*(11), 1821–1839.

Wang, Y., et al. (2022). Signaling transduction of ABA, ROS, and Ca^{2+} in plant stomatal closure in response to drought. *International Journal of Molecular Sciences, 23*, 14824.

Yang, Y., Guo, Y., & Xu, Y. (2020). Calcium signaling in plant drought stress response. *Plant Signaling & Behavior, 15*, 1–12.

Yoshida, T., Mogami, J., & Yamaguchi-Shinozaki, K. (2014). ABA-dependent and ABA-independent signaling in response to osmotic stress in plants. *Current Opinion in Plant Biology, 21*, 133–139.

Zhu, J.-K. (2016). Abiotic stress signaling and responses in plants. *Cell, 167*(2), 313–324.

Volume: 06 Issue No: 09

FROM DNA TO DINNER PLATE: THE ROLE OF BIOTECHNOLOGY IN ENDING HUNGER

Article ID: AG-V06-I09-71

Santhiya Shree K

M.Sc. (Ag.) Molecular Biology and Biotechnology, Department of Plant Biotechnology, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Introduction

Every few seconds, somewhere in the world, a family sits down to a meal that is too small. Nearly 700 million people go to bed hungry each night, and almost a third of the planet cannot reliably count on their next meal. Feeding a global population racing toward 9.7 billion by 2050 — on the same finite land, with a warming climate and shrinking water tables — is arguably the defining logistical challenge of this century. Increasingly, the tools being reached for are not just tractors and fertiliser sacks, but pipettes, gene guns and the humble bacterium. The word “hunger” ranges in meaning from short-term physical discomfort caused by lack of food to life-threatening food deprivation, and encompasses broader issues related to food access, socioeconomic inequalities and human dignity. Hunger is associated with **consumption of an insufficient amount of dietary energy to maintain a normal, active, healthy life.**

An estimated **645 million people** (approximately 7.8 percent of the global population) may have faced hunger in 2025. In 2025, hunger affected 309 million people in Africa, 292 million in Asia and 32 million in Latin America while progress towards the Sustainable Development Goal of Zero Hunger remains insufficient.

Hunger remains one of humanity's greatest challenges despite remarkable advances in agricultural productivity. **The problem does not only relate with producing more food; it also involves climate change, declining natural resources, crop losses, malnutrition, food prices, postharvest losses, conflicts and unequal access to nutritious food**. Imagine a world in which farmers can grow crops that survive drought, rice can tolerate flooding, wheat can withstand disease, vegetables retain their nutrients after harvest, microorganisms produce nutritious food

ingredients and crop waste can be converted into valuable products. But many of these technologies already exist in laboratories, research programmes and commercial food systems. At the same time, hunger remains a reality.

Biotechnology acts as a toolbox to address several of these challenges. Conventional plant biotechnology, marker-assisted breeding, genomic selection, genetic engineering, CRISPR-based genome editing, biofortification, microbial biotechnology, fermentation technology, tissue culture and postharvest biotechnology can contribute to improved crop productivity, nutritional quality, stress tolerance, disease resistance and food preservation. At the same time, biotechnology cannot independently solve the economic and social causes of hunger. Access to land, water, markets, seeds, infrastructure, technology and affordable nutritious food remains equally important. This article explores how modern biotechnology can contribute to global food security, its major applications, limitations and ethical considerations, and the possibility of integrating biotechnology with sustainable agriculture to create a more resilient food system.

From Better Seeds to Better Food: How Modern Biotechnology Could Build a Food-Secure Future

2. WHAT DOES "ENDING HUNGER" ACTUALLY MEAN?

Ending hunger is more complicated than simply increasing crop yield. The concept of food security generally encompasses four major dimensions:

1. Availability

Is enough food being produced?

2. Access

Can people physically and economically obtain food?

3. Utilization

Is the food nutritious and safe enough to support healthy lives?

4. Stability

Can people maintain access to food despite droughts, floods, economic shocks, conflicts and other disruptions?

Therefore:

Food security = Food availability + Access + Utilization + Stability

Biotechnology can contribute particularly to the availability, nutritional quality, safety and stability components.

However, economic access and distribution require broader social and policy interventions.

3. THE BIOTECHNOLOGIST'S TOOLKIT:

"Biotechnology in agriculture" is not a single technique but a family of them, each suited to a different problem.

Genetic Modification (GM)

Genetic modification involves inserting a gene — sometimes from an entirely different species — into a crop's genome to confer a specific trait. The most widely grown GM crops today carry genes for insect resistance (such as the Bt gene from the soil bacterium Bacillus thuringiensis) or herbicide tolerance, which together have allowed farmers to cut pesticide use and reduce crop losses. Bt cotton, for instance, transformed cotton farming across South Asia by sharply reducing losses to the bollworm, one of the crop's most destructive pests.

Marker-Assisted Selection

This technique uses knowledge of a plant's genome to identify DNA "markers" linked to desirable traits — drought tolerance, disease resistance, faster maturity — allowing breeders to screen thousands of seedlings in the laboratory rather than waiting years to see which plants perform well in the field. It speeds up conventional breeding without introducing foreign genes, which has made it far less controversial than GM technology while still delivering major gains, including flood-tolerant "scuba rice" varieties that can survive being fully submerged for two weeks.

Genome Editing (CRISPR)

Where GM technology inserts new genetic material, genome editing tools such as CRISPR-Cas9 act more like a word processor's find-and-replace function, making precise edits to a plant's own existing DNA. Because no foreign genes need be introduced, many countries are now regulating gene-edited crops more like conventionally bred varieties than like GM organisms, which has accelerated research into disease-resistant bananas, low-gluten wheat, browning-resistant mushrooms and tomatoes with extended shelf life.

Biofortification

Rather than modifying a crop to survive better, biofortification modifies it to nourish better, boosting the levels of vitamins and minerals in the edible parts of staple foods. This can be achieved through conventional breeding, as with orange-fleshed sweet potato bred for higher

beta-carotene content, or through genetic engineering, as with Golden Rice, engineered to produce beta-carotene, a precursor of vitamin A, in its grain.

Microbial and Cellular Biotechnology

Beyond the crop itself, biotechnology is reshaping what surrounds it. Engineered biofertilisers and biopesticides use beneficial microbes to improve soil nitrogen fixation and suppress pests without heavy chemical inputs. Tissue-culture propagation allows disease-free planting material to be mass-produced for crops like bananas and cassava that are usually propagated from cuttings and vulnerable to inherited disease. And at the more experimental end, precision fermentation and cultivated ("lab-grown") proteins are being explored as ways to produce dairy proteins, egg proteins and meat analogues with a far smaller land and water footprint than conventional livestock farming.

Challenge	**Biotechnology solution**	**Potential contribution**
Drought	Molecular breeding, CRISPR	Stress resilience
Heat	Gene editing, marker-assisted breeding	Stable productivity
Salinity	Molecular breeding, genome editing	Salt tolerance
Diseases	Resistant genes, CRISPR, diagnostics	Reduced crop losses
Insect pests	Bt technology, biopesticides	Crop protection
Micronutrient deficiency	Biofortification	Improved nutrition
Poor planting material	Tissue culture	Healthy, uniform plants
Postharvest losses	Edible coatings, biopackaging	Extended shelf life
Food safety	Biosensors, molecular diagnostics	Faster detection
Agricultural waste	Microbial biotechnology	Waste valorization
Protein production	Precision fermentation	Alternative food ingredients
Nutrient deficiency in soil	Biofertilizers	Improved nutrient availability

4. CRISPR: Editing Crops

Among recent biotechnology innovations, CRISPR-based genome editing has attracted enormous attention.

CRISPR-Cas systems can be programmed to target specific DNA sequences.

The technology has rapidly expanded beyond Cas9, with different Cas proteins and engineered variants offering increasingly diverse genome-engineering capabilities. A 2025 review in *Nature Reviews Molecular Cell Biology* highlighted the rapid development of CRISPR technologies for crop improvement and their potential to produce crops with higher yields and greater resilience.

CRISPR-based crop improvement is being investigated for:

- Drought tolerance
- Heat tolerance
- Salinity tolerance
- Disease resistance
- Improved nutrient-use efficiency
- Yield-related traits and Nutritional enhancement
- Grain and fruit quality

For example:

The goal is not to create an imaginary "super plant."

Rather, the objective is to improve specific traits that matter to farmers and consumers.

5. BIOTECHNOLOGY AT WORK:

Golden Rice and the Fight Against Hidden Hunger

Vitamin A deficiency remains a leading cause of preventable childhood blindness and contributes to hundreds of thousands of child deaths a year, concentrated in regions where rice is the dietary staple but supplies little vitamin A. Golden Rice, engineered to biosynthesise beta-carotene in the grain itself, was designed as a low-cost, self-renewing complement to supplementation and fortification programmes. After two decades of research and regulatory review, the Philippines approved Golden Rice for commercial cultivation in 2021, making it the first genetically engineered crop specifically designed to address a nutritional deficiency to reach farmers' fields. Its path has not been smooth: legal challenges from environmental groups led a Philippine appeals court to revoke its commercial permit in 2024, and the case remains before



the courts, illustrating just how tightly public trust, regulation and technology are entangled in this field.

***B*t Cotton and Bt Brinjal in South Asia**

Bt cotton, engineered for resistance to bollworm pests, was adopted rapidly across India and Bangladesh, becoming one of the most widely planted GM crops in South Asia and significantly cutting insecticide sprays and associated farmer health risks in many growing regions. Building on that experience, Bangladesh approved Bt brinjal (eggplant), the country's first genetically engineered food crop, which has allowed farmers to sharply reduce pesticide applications against the destructive fruit and shoot borer while improving yields for a vegetable that is a dietary staple across the region.

Flood- and Drought-Tolerant Rice

Using marker-assisted breeding, scientists identified and transferred a submergence-tolerance gene into popular rice varieties across South and Southeast Asia, producing "scuba rice" that can survive prolonged flooding, a growing risk as extreme weather events intensify. Complementary drought-tolerant varieties are helping rainfed farming regions in sub-Saharan Africa and South Asia hold on to yields during erratic monsoons.

Disease-Resistant Cassava and Banana

Cassava and banana are dietary lifelines for hundreds of millions of people across Africa, yet both are propagated vegetatively, which allows viral diseases to spread silently through planting material. Biotechnology-assisted disease diagnostics, virus-free tissue-culture seedlings and gene-edited resistance to diseases such as cassava mosaic virus and banana bacterial wilt are helping protect these crops from epidemics that have historically wiped out entire harvests.

6. BEYOND THE FIELD: FROM HARVEST TO SHELF

Ending hunger is not only about growing more food; it is about losing less of what is already grown. In many developing regions, a third or more of harvested food never reaches a plate, spoiling in transit or storage long before it reaches a market. Biotechnology contributes here too, through genetically improved crop varieties with longer shelf life and slower browning or spoilage, engineered enzymes that improve food processing efficiency, and biosensors that

can detect spoilage or contamination in the supply chain. Fortified and biofortified staples, meanwhile, allow nutrition improvements to travel through existing food systems without requiring people to change their diets or afford new foods — an important consideration in resource-poor settings. Postharvest biotechnology can help reduce these losses.

Technologies include:

- Edible coatings
- Biodegradable packaging
- Antimicrobial films
- Controlled-atmosphere technologies
- Natural preservatives
- Enzyme-based treatments
- Biocontrol microorganisms

7. Plant Tissue Culture: Multiplying the Best Plants

Plant tissue culture is another important biotechnology with direct agricultural applications. Through techniques such as micropropagation, large numbers of genetically uniform, disease-free plants can be produced from selected plant material. It is particularly valuable for crops such as Banana, Potato, Sugarcane, Strawberry, Ornamentals, Several horticultural crops Tissue culture can provide rapid multiplication of elite planting material. It also supports:

- Virus elimination
- Germplasm conservation
- Haploid production
- Secondary metabolite production
- Genetic transformation
- Breeding programmes

8. THE ROAD BLOCKS:

Several genuine obstacles slow its path from laboratory to dinner plate.

- Public trust and perception: Decades of polarised debate over GM foods have left many consumers wary, regardless of the specific technology or trait involved, and scientific reassurances about safety often struggle to compete with emotionally resonant fears.
- Regulatory complexity: Approval pathways for genetically modified and gene-edited crops differ enormously between countries, and a technology approved in one nation may remain

tied up in review, litigation or outright bans in another, as Golden Rice's ongoing legal battles in the Philippines illustrate.

- Intellectual property and access: When crop biotechnology is controlled by a small number of large agribusiness firms, the benefits can be slow to reach smallholder farmers unless publicly funded or philanthropic institutions actively work to make seeds affordable and freely available, as has been the case with Golden Rice and several Bt crop programmes.
- Biosafety and ecological concerns: Legitimate scientific questions remain about gene flow to wild relatives, impacts on non-target species and the long-term durability of pest and disease resistance, all of which require ongoing monitoring rather than one-time approval.
- Equity of benefit: Technologies developed for large-scale commercial agriculture do not always translate easily to the small, diverse, resource-constrained farms that feed much of the developing world, meaning research priorities must be deliberately aligned with smallholder needs rather than assumed to trickle down.

Conclusion

The Green Revolution demonstrated how improved varieties, fertilizers, irrigation and crop management could dramatically increase food production. The goal is not simply: More yield but: More yield + better nutrition + climate resilience + lower resource use + reduced losses + food safety. This is where modern biotechnology becomes especially powerful. None of this suggests biotechnology alone can end hunger. Chronic hunger is as much a problem of poverty, conflict, infrastructure, trade policy and inequality as it is a problem of crop science. A drought-tolerant seed variety cannot fix a broken supply chain, and a vitamin-fortified grain cannot substitute for a stable income. But as one tool among many — alongside better storage, fairer markets, resilient irrigation and sound nutrition policy — biotechnology offers something increasingly scarce in the fight against hunger: speed. In a world where climate change is compressing the time available to adapt, the ability to develop a drought-tolerant variety in a few growing seasons rather than a few decades may be the difference between a community that survives a bad year and one that does not. Biotechnology provides an extraordinary collection of tools capable of transforming agriculture and food production. From CRISPR-edited climate-resilient crops to biofortified staples, microbial biofertilizers, precision fermentation, tissue culture, molecular diagnostics and postharvest technologies, biotechnology can address multiple points along the food chain. Genomics can identify the problem, CRISPR can modify the target,

AI can accelerate discovery, Microbial biotechnology can improve production, Food biotechnology can improve preservation and nutrition, Farmers can turn these innovations into food. But technology must reach the people who need it most. The future of food security will therefore depend not on biotechnology alone, but on the integration of science, sustainable agriculture, farmer participation, public policy, infrastructure, equitable access and responsible innovation. The goal should not simply be to produce more food. It should be to create a food system in which every person has reliable access to sufficient, safe, affordable and nutritious food—even in a changing climate.

References

Ahmed, S., Rashid, M. A., Hoque, M. E., et al. (2020). Impacts of Bt brinjal (eggplant) technology in Bangladesh. International Food Policy Research Institute (IFPRI), Washington, DC.

De Steur, H., Stein, A. J., & Demont, M. (2022). From Golden Rice to Golden Diets: How to turn its recent approval into practice. Global Food Security, 32, 100596. https://doi.org/10.1016/j.gfs.2021.100596

Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development, UNICEF, World Food Programme, & World Health Organization. (2026). The State of Food Security and Nutrition in the World 2026: Understanding and addressing the high cost of a healthy diet. FAO.

Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development, UNICEF, World Food Programme, & World Health Organization. (2025). The State of Food Security and Nutrition in the World 2025. FAO.

Stokstad, E. (2019). After 20 years, Golden Rice nears approval. Science, 366(6468), 934. https://doi.org/10.1126/science.366.6468.934

Volume: 06 Issue No: 09

SPEED BREEDING FOR GENOMIC SELECTION AND ITS APPLICATIONS

Article ID: AG-VO6-I09-72

Gude Sai Manideep, Peta.Thahera, Dasari.Tribhuvana and Kolimigundla Amarnath*

Department of Genetics and Plant Breeding

Vignan Institute of Agriculture and Technology, Vignan's Foundation for Science, Technology and Research, Vadlamudi, Guntur 522213, India

*Corresponding Author: Kolimigundla Amarnath

Introduction

Increasing food demand, climate change, limited natural resources, and emerging pests and diseases have created a need for faster and more efficient crop improvement strategies. Conventional breeding often requires several generations to develop and evaluate superior plants, resulting in lengthy breeding cycles. **Speed breeding (SB)** has emerged as an effective approach to overcome this limitation by manipulating environmental conditions such as photoperiod, temperature, and light intensity to accelerate plant growth and flowering. The modern speed-breeding approach gained significant attention through the work of Watson et al. (2018**)**, who demonstrated that optimized controlled-environment conditions could enable rapid generation advancement in several major crops. **Genomic selection (GS),** proposed by Meuwissen, Hayes, and Goddard (2001), further strengthened breeding efficiency by using genome-wide molecular markers to predict the genetic potential of individuals at an early stage. The integration of speed breeding with genomic selection combines rapid generation advancement with early genomic-based selection, thereby reducing breeding cycle time and increasing genetic gain. This integrated approach has considerable potential for accelerating the development of high-yielding, disease-resistant, stress-tolerant, and climate-resilient crop varieties.

Importance of Speed Breeding for Genomic Selection

1. **Shortens the Breeding Cycle:** Speed breeding enables rapid generation advancement, allowing genomic selection to be repeated across generations within a shorter period.
2. **Accelerates Genetic Gain:** Combining rapid generation turnover with genomic prediction increases the rate at which desirable genetic combinations can be selected and accumulated.
3. **Enables Early Selection:** Genomic selection can identify superior individuals at an early growth stage, while speed breeding rapidly advances the selected plants to subsequent generations.
4. **Facilitates Rapid Trait Fixation:** Repeated cycles of selection and generation advancement help accelerate the fixation of favorable alleles and the development of genetically stable lines.
5. **Improves Breeding Efficiency:** The integration of speed breeding and genomic selection reduces dependence on lengthy phenotypic evaluations during the early generations.
6. **Supports Complex Trait Improvement:** The combined approach is particularly useful for traits such as yield, disease resistance, drought tolerance, heat tolerance, and nutritional quality, which are controlled by multiple genes.
7. **Enhances Selection Intensity:** Rapid generation advancement allows breeders to handle and select from larger breeding populations within the same timeframe, increasing opportunities to identify superior genotypes.
8. **Accelerates Variety Development:** SB–GS can shorten the overall breeding pipeline and facilitate the development of high-performing, climate-resilient crop varieties.

How It Works

Speed breeding (SB) and genomic selection (GS) function as complementary approaches in modern crop improvement. Speed breeding accelerates generation advancement by optimizing environmental conditions such as photoperiod, temperature, light intensity, and plant density. Genomic selection, in contrast, uses genome-wide molecular marker information to predict the genetic potential of breeding individuals, allowing promising genotypes to be identified at an early stage.

The process begins with the selection of diverse parents, followed by crossing to generate breeding populations. In the early generations, individuals are genotyped using high-density

molecular markers or single nucleotide polymorphism (SNP) arrays. Phenotypic and genotypic information from a training population is then used to develop a genomic prediction model for estimating genomic estimated breeding values (GEBVs) of individuals in the selection population. Individuals with higher predicted genetic merit can be selected before extensive field evaluation. The selected individuals are subsequently grown under speed-breeding conditions to promote rapid flowering and seed production. This reduces the generation interval and allows selected breeding material to be advanced to subsequent generations more quickly. Genomic prediction and selection can then be repeated across successive generations, facilitating the accumulation of favourable alleles and accelerating genetic improvement.

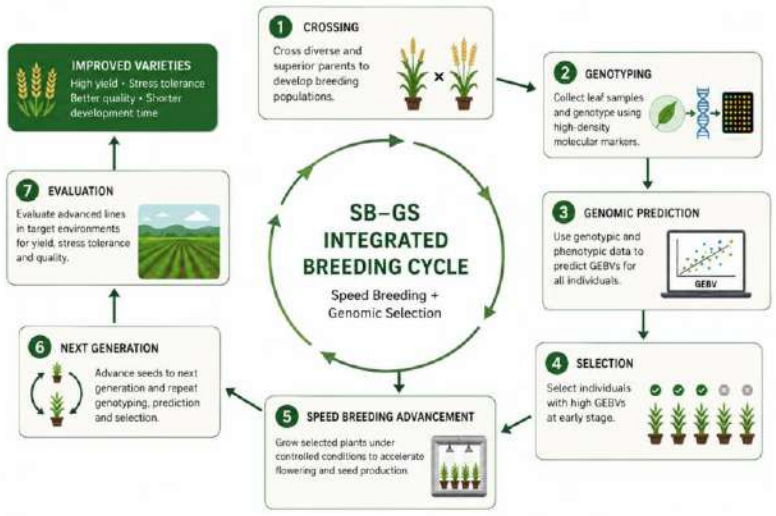


Fig. 1: Mechanism of Speed Breeding integrated with Genomic Selection (SB–GS) for accelerated crop improvement.

After several cycles of SB–GS, advanced breeding lines are evaluated under target environments for important traits such as yield, stress tolerance, and quality. The most promising lines are further tested through multi-location trials and, after successful evaluation, may be considered for release as improved crop varieties.

Environmental Requirements for Speed Breeding

Speed breeding relies on carefully controlled environmental conditions to promote vigorous plant growth, earlier flowering, and rapid seed production. Temperature, relative humidity, light intensity, and photoperiod are the major factors that influence the success of a speed-breeding system.

- **Temperature:** An optimum temperature should be maintained according to the requirements of the crop being grown. Many speed-breeding systems use temperatures of approximately **22–25°C during the light period**, with slightly lower temperatures during the dark period. However, the suitable temperature range varies among crop species and genotypes.
- **Relative Humidity:** Maintaining relative humidity at approximately **50–70%** can support healthy plant growth while reducing excessive moisture and the associated risk of fungal infection and physiological stress.
- **Light Intensity:** Sufficient light is essential for healthy vegetative growth and reproductive development. **Supplemental LED lighting** can be used to provide the required light intensity, particularly when natural light is insufficient.
- **Photoperiod:** An extended photoperiod is a key component of many speed-breeding protocols. Photoperiods of approximately **20–22 hours of light followed by 2–4 hours of darkness per day** are commonly used to promote earlier flowering and reduce the generation interval. The optimum photoperiod depends on the crop and its sensitivity to day length.
- **Other Conditions:** In addition to the major environmental factors, **irrigation, nutrient supply, plant density, ventilation, and carbon dioxide availability** should be appropriately managed to maintain healthy growth and support efficient generation advancement.

The specific environmental conditions should be optimized according to the **crop species, genotype, and growth stage**, as speed-breeding requirements are not identical across crops.

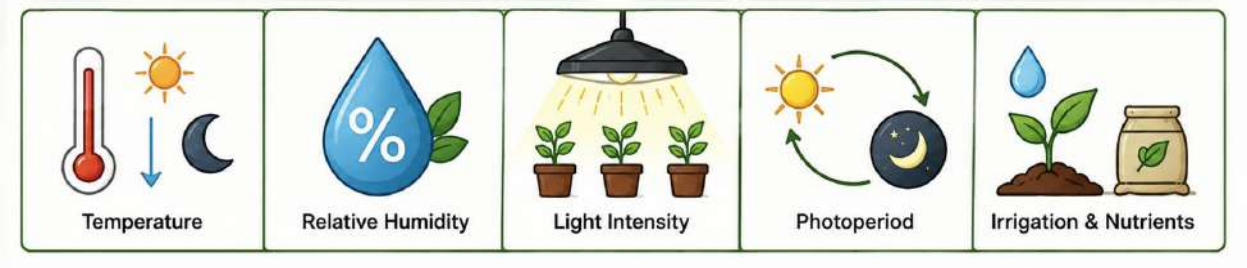


Fig. 2. Major environmental requirements for speed breeding, including temperature, relative humidity, light intensity, photoperiod, irrigation, and nutrient management.

Applications of Speed Breeding in Genomic Selection

The integration of speed breeding with genomic selection provides a practical framework for improving the efficiency and precision of modern crop breeding. By combining rapid generation advancement with genome-wide selection, SB–GS can be applied to accelerate the improvement of complex and economically important traits. Its major applications include increasing genetic gain, improving selection efficiency, accelerating trait improvement, and developing crop varieties adapted to challenging environments.



Fig. 3. Major applications of speed breeding integrated with genomic selection in crop improvement.

Recent Success Stories

1. **Accelerated Wheat Improvement Using Speed Breeding and Genomic Selection University of Queensland, Australia**
   - **Breeding strategy:** Speed breeding was integrated with genomic selection to shorten generation intervals and increase the rate of genetic improvement in wheat.
   - **Key achievement:** Controlled-environment conditions enabled the advancement of up to six wheat generations per year, while genomic selection supported the early identification of promising breeding materials.

- **Research impact:** The combined approach demonstrated the potential to accelerate the development of wheat lines with improved yield potential, disease resistance, and adaptation to climatic stresses.

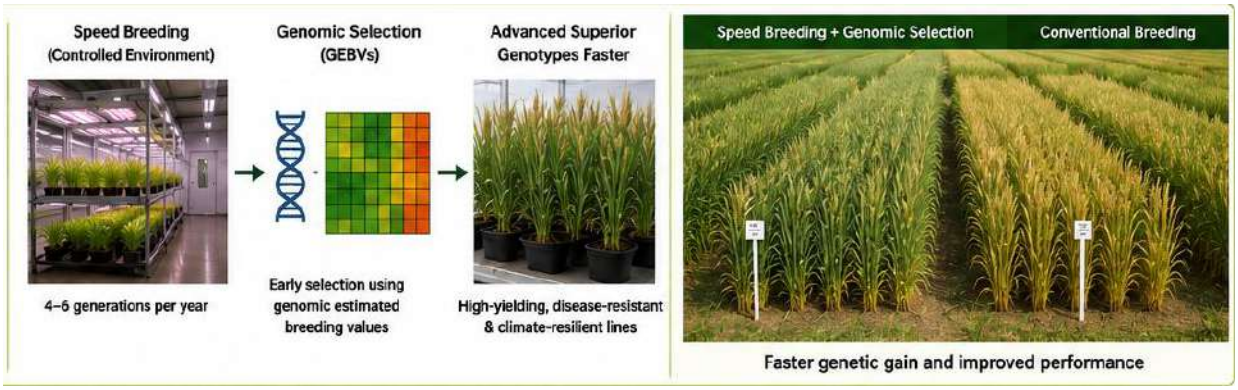


Fig. 4. Accelerated wheat improvement using speed breeding and genomic selection at the University of Queensland, Australia.

2. Rapid Cycling Genomic Selection in Maize – CIMMYT

- **Breeding strategy:** Genomic estimated breeding values (GEBVs) were integrated with rapid generation advancement to increase the frequency of selection and enable multiple breeding cycles within a year.
- **Key achievement:** Several genomic selection cycles could be completed within a single year, substantially reducing the time required for advancing and selecting superior maize material.
- **Research impact:** Rapid cycling increased the rate of genetic gain for grain yield and stress tolerance, while accelerating the development and improvement of elite maize germplasm.

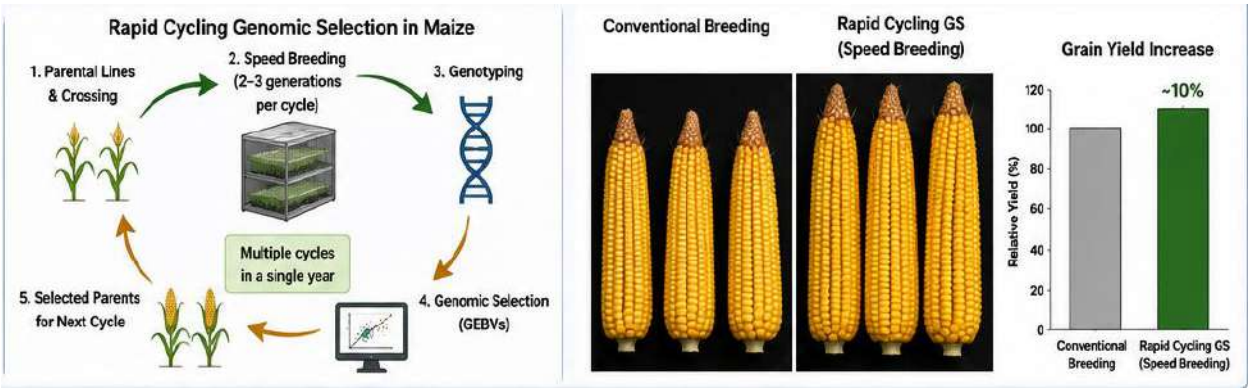


Fig. 5. Rapid cycling genomic selection in maize at CIMMYT for accelerated genetic gain and improved grain yield.

3. Genomic Selection-Assisted Chickpea Improvement

- **Breeding strategy:** Genomic selection was combined with rapid generation advancement to facilitate the efficient identification and development of chickpea lines adapted to drought-prone and water-limited environments.
- **Key achievement:** The integrated approach enabled faster identification and advancement of superior breeding lines with improved yield and adaptation under moisture-limited conditions.
- **Research impact:** This breeding strategy supported the development of climate-resilient chickpea germplasm and helped reduce the time required to generate improved breeding material for semi-arid environments.

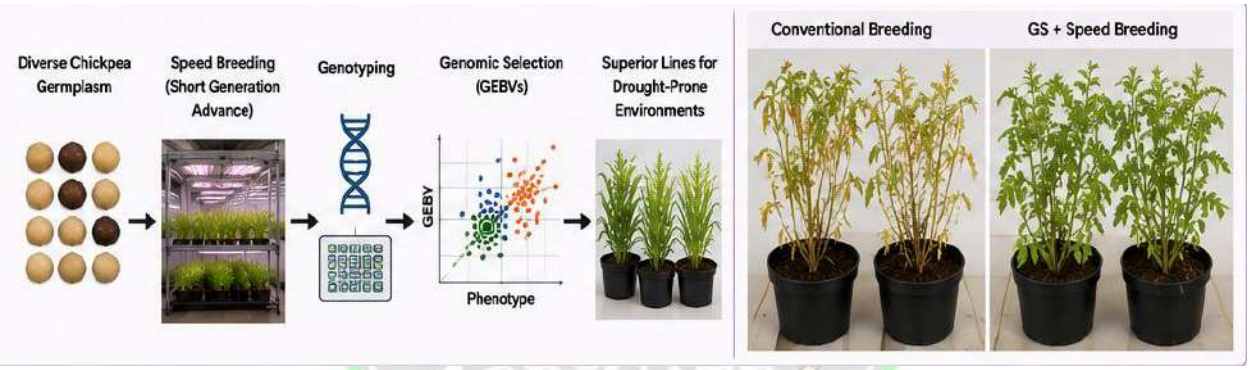


Fig. 6. Genomic selection-assisted chickpea improvement at ICRISAT, India, for enhanced yield and adaptation to drought-prone environments.

Future Perspective

The integration of speed breeding with genomic selection offers considerable scope for further improvement in crop breeding. Future studies can focus on combining SB–GS with high-throughput phenotyping, advanced genomic tools, and computational approaches to improve the accuracy and efficiency of selection. Greater application of this approach to drought, heat, disease resistance, yield stability, and nutritional traits could contribute to the development of crop varieties better suited to changing environmental conditions.

Conclusion

Speed breeding and genomic selection provide a complementary strategy for accelerating modern crop improvement. By combining rapid generation advancement with early genomic-based selection, breeders can reduce generation intervals and increase the efficiency of selecting superior genotypes. Applications in wheat, maize, and chickpea demonstrate the potential of SB–

GS to improve yield, stress tolerance, and environmental adaptation. Continued development and field-level validation of SB–GS could further shorten breeding pipelines and accelerate the development of productive, climate-resilient, and sustainable crop varieties.

References

Pogu, A.S., & Soharu, A. (2025). Speed breeding in wheat crop: A comprehensive review. *Journal of Advances in Biology & Biotechnology*, 28(6), 235–246.

Ćeran, M., Miladinović, D., Đorđević, V., Trkulja, D., Radanović, A., Glogovac, S., & Kondić-Špika, A. (2024). Genomics-assisted speed breeding for crop improvement: Present and future. *Frontiers in Sustainable Food Systems*, 8, 1383302.

Pandey, S., Sood, S., Reddy, Y.S., & Laxman, R.H. (2024). Improving genetic gain through digitalization and speed breeding in crop plants: An overview. *International Journal of Innovative Horticulture*, 13(2), 124–132.

He, R., Ju, J., Liu, K., Song, J., Zhang, S., Zhang, M., Hu, Y., Liu, X., Li, Y., & Liu, H. (2024). Technology of plant factory for vegetable crop speed breeding. *Frontiers in Plant Science*, 15, 1414860.

Kumar, K.P., & Walia, P. (2024). Speed breeding in cereal crops: Accelerating genetic improvement for rapid agricultural advancement. *Journal of Experimental Agriculture International*, 46(6), 465–477.

Samineni, S., Sen, M., Sajja, S.B., & Gaur, P.M. (2020). Rapid generation advance (RGA) in chickpea to produce up to seven generations per year and enable speed breeding. *The Crop Journal*, 8(1), 164–169.

Ghosh, S., Watson, A., Gonzalez-Navarro, O.E., Ramirez-Gonzalez, R.H., Yanes, L., Mendoza-Suárez, M., Simmonds, J., Wells, R., Rayner, T., Green, P., et al. (2018). Speed breeding in growth chambers and glasshouses for crop breeding and research. *Nature Protocols*, 13, 2944–2963.

Watson, A., Ghosh, S., Williams, M.J., Cuddy, W.S., Simmonds, J., Rey, M.D., Hatta, M.A.M., Hinchliffe, A., Steed, A., Reynolds, D., et al. (2018). Speed breeding is a powerful tool to accelerate crop research and breeding. *Nature Plants*, 4, 23–29.

Zhang, X., Pérez-Rodríguez, P., Semagn, K., Beyene, Y., Babu, R., & Crossa, J. (2017). Rapid cycling genomic selection in a multiparental tropical maize population. *G3: Genes, Genomes, Genetics*, 7(7), 2315–2326.

Crossa, J., Pérez-Rodríguez, P., Cuevas, J., Montesinos-López, O., Jarquín, D., de los Campos, G., Burgueño, J., González-Camacho, J.M., Pérez-Elizalde, S., Beyene, Y., et al. (2017). Genomic selection in plant breeding: Methods, models, and perspectives. *Trends in Plant Science*, 22(11), 961–975.

de los Campos, G., Hickey, J.M., Pong-Wong, R., Daetwyler, H.D., & Calus, M.P.L. (2013). Whole-genome regression and prediction methods applied to plant breeding. *Genetics*, 193(2), 327–345.

Volume: 06 Issue No: 09

TURNING SALINITY INTO A RESOURCE: EXTRACTION, RECOVERY AND VALORISATION OF SALTS FROM SALINE SOILS

Article ID: AG-V06-I09-73

M. P. Abi

1st M.Sc.(Ag.)Soil Science, Department of Soil Science and Agricultural Chemistry

Department of Natural Resource Management, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, 641003, India

Abstract

Salt-affected soils cover more than a billion hectares worldwide and are usually treated purely as a constraint to be leached away and discharged. This article reframes saline soils as a resource base rather than a liability, outlining how the very salts responsible for reduced crop yields can be systematically extracted, recovered and valorised. It reviews established and emerging extraction routes — surface scraping, leaching with controlled drainage, bio-drainage and phytoextraction using halophytes, and solar or photothermal evaporation systems — along with methods for concentrating and recovering the resulting salts. It then surveys valorisation pathways, including industrial salts, gypsum and phosphogypsum-based soil amendments, saline aquaculture, biosaline agriculture and halophyte biomass products. Framing salinity management around resource recovery can lower reclamation costs, generate secondary income streams and support a circular, low-waste approach to managing salt-affected land.

Keywords: Saline soil, salinity management, salt extraction, resource recovery, valorisation, circular economy

Introduction

Soil salinization is one of the most widespread forms of land degradation, affecting over 1,030 million hectares globally and threatening nearly half of the world's arable land by 2050 if left unmanaged. Salt-affected soils accumulate soluble salts of sodium, calcium, magnesium and sulphate in the root zone, raising the electrical conductivity of the soil solution, disrupting plant water uptake through osmotic stress, and often degrading soil structure through sodium-induced

dispersion of clay particles. Arid and semi-arid regions, poorly drained irrigated tracts, and coastal areas exposed to seawater intrusion are particularly vulnerable.

Conventional reclamation has focused almost entirely on removing salts from the crop root zone through leaching, drainage and chemical amendments, with the leached salts either discharged into drains, rivers or evaporation basins, or simply left to accumulate downstream. This approach treats salinity purely as a problem to be pushed elsewhere rather than a stream of valuable minerals sitting in the soil profile. A growing body of research is instead asking whether the salts removed during reclamation can be captured, concentrated and put to productive use — turning a costly environmental liability into a source of industrial raw material, soil amendments and additional farm income. This article brings together current thinking on salt extraction techniques, recovery methods and valorisation pathways for salt-affected soils.

Contents

The Scale and Nature of the Salinity Problem

Salt-affected soils are broadly classed as saline, sodic, or saline-sodic depending on the dominant ions present and the resulting soil chemistry. Saline soils are dominated by soluble neutral salts such as sodium chloride and sodium sulphate; sodic soils carry high exchangeable sodium percentages that degrade soil structure even at moderate salt concentrations; and saline-sodic soils combine both problems. The composition of the salt load — chlorides, sulphates, bicarbonates, calcium, magnesium and sodium in varying proportions — determines both the reclamation strategy required and the commercial value of any salts recovered.

Techniques for Extracting Salts from Saline Soils

Salt scraping is the simplest physical method, in which the visible surface salt crust that forms through capillary rise and evaporation is mechanically removed. It gives quick but temporary relief and needs to be paired with measures that address the deeper salt reserve in the soil profile.

Leaching remains the most widely practised extraction method: excess low-salinity water is applied to dissolve accumulated salts and carry them below the root zone or into a drainage network. As a rule of thumb, roughly 30 cm of water passing through the soil removes around 80 percent of the soluble salts present in the corresponding 30 cm depth, provided drainage is adequate. Where natural drainage is poor, subsurface tile drains or bio-drainage using deep-

rooted, high-water-use trees can lower the water table and intercept the leachate before it can re-salinize the surface.

Phytoextraction using halophytes offers a biological route to salt removal. Salt-tolerant plants such as *Salicornia, Suaeda, Atriplex and Sesuvium* species accumulate substantial quantities of sodium and chloride in their shoot tissue as part of their own osmotic adjustment. Repeated cropping and removal of this biomass steadily draws down the salt pool in the surface soil, and can extend the depth and duration over which desalinization proceeds compared with leaching alone, although very high initial salinity or unfavourable climate can limit halophyte establishment.

More recently, solar and photothermal evaporation systems have been developed to couple soil desalinization with resource recovery in a single step. In these systems, saline leachate collected from washed soil is passed through solar-driven interfacial evaporators that concentrate the brine, recover clean water for reuse in irrigation, and leave behind a solid salt residue for collection, in some cases with essentially zero liquid discharge. Reported techno-economic assessments suggest such integrated wash–evaporate–irrigate systems can achieve competitive per-tonne remediation costs while simultaneously producing freshwater and marketable salt.

Recovery and Processing of Extracted Salts

Once salts are mobilized into leachate or drainage water, recovery depends on concentrating the brine and separating individual salt fractions. Simple options include evaporation ponds, where solar energy gradually concentrates drainage water until salts crystallize and can be harvested; engineered solar evaporators and photothermal collectors, which accelerate this process and recover freshwater alongside the salt; and staged or fractional crystallization, which exploits the different solubilities of sodium chloride, sodium sulphate, calcium sulphate (gypsum) and magnesium salts to separate them into relatively pure fractions rather than a single mixed residue. The choice of method depends on the volume of leachate, local solar radiation and land availability, and the value of the specific salts targeted for recovery.

Valorisation Pathways for Recovered Salts

Recovered salts have several potential end uses depending on their purity and composition. Sodium chloride-rich fractions can be directed toward industrial and non-food uses

such as de-icing, tanning, textile processing and as a feedstock for chlor-alkali chemistry, subject to purity and regulatory checks. Calcium-rich by-products, including natural and industrial gypsum such as phosphogypsum, are widely used as soil amendments in their own right: added back to sodic soils, they supply calcium that displaces exchangeable sodium from clay surfaces, improving soil structure and infiltration while also giving a productive outlet for a material otherwise regarded as waste.

Beyond direct salt recovery, saline water and salt-affected land can support biosaline agriculture and saline aquaculture, in which salt-tolerant crop varieties, halophytic forages, or brackish-water fish and shrimp are cultivated on land or in water considered unfit for conventional use. Halophyte biomass harvested during phytoextraction is not merely a waste stream either: species such as Salicornia have value as forage, as a source of edible greens, and as feedstock for extracting bioactive compounds and biofuel precursors, adding a further layer of economic return to the reclamation process.

Economic and Environmental Benefits of a Resource-Recovery Approach

Framing salinity management around extraction and valorisation, rather than simple disposal, offers several advantages. It can offset part of the cost of reclamation through the sale of recovered salts, gypsum products or halophyte biomass; it reduces the volume of saline effluent discharged to drains and water bodies, lowering downstream environmental impact; and it supports a circular-economy model in which a degraded resource — salt-affected soil — is converted into multiple usable outputs instead of a single restored but otherwise unproductive field. Realizing these benefits at scale will require further work on techno-economic assessment, quality standards for recovered salts, and extension support to help farmers and land managers adopt these integrated approaches.

Conclusion

Salt-affected soils will remain a major constraint on global food production unless reclamation strategies evolve beyond simple leaching and disposal. Combining proven techniques — leaching and drainage, halophyte-based phytoextraction, and emerging solar evaporation technologies — with deliberate recovery and valorisation of the extracted salts can convert a costly environmental problem into a source of industrial raw materials, soil amendments and additional farm income. Wider adoption of this resource-recovery mindset,

backed by further technical and economic research, can make salinity management more sustainable and more attractive to the farmers and land managers who deal with it every season.

References

Yu H., Liu Y., Wang X., Zhang L. and Pi K. 2025. Solar evaporation-driven integrated system for saline soil remediation, freshwater recovery, salt resource harvest, and agricultural irrigation. Water Res. 287: 124288.

Shaygan M. and Baumgartl T. 2022. Reclamation of salt-affected land: a review. Soil Syst. 6(3): 61.

Elmeknassi M., Elghali A., de Carvalho H. W. P., Laamrani A. and Benzaazoua M. 2024. A review of organic and inorganic amendments to treat saline-sodic soils: emphasis on waste valorisation for a circular economy approach. Sci. Total Environ. 921: 171087.

Leake J. E., Squires V. and Shabala S. 2022. Rethinking rehabilitation of salt-affected land: new perspectives from Australian experience. Earth 3(1): 16.

Food and Agriculture Organization of the United Nations (FAO). 1988. Salt-Affected Soils and their Management. FAO Soils Bulletin 39, Rome.

Food and Agriculture Organization of the United Nations (FAO) and ITPS. 2015. Status of the World's Soil Resources – Main Report. FAO, Rome.

Volume: 06 Issue No: 09

HIGH SEAS FISHERIES: TRENDS, CHALLENGES, GOVERNANCE AND FUTURE DIRECTIONS

Article ID: AG-V06-I09-74

R. G. Sasikumar

Department of Fisheries Biology and Resource Management

Fisheries College and Research Institute, Thoothukudi, Tamil Nadu, India

Abstract

High seas fisheries exploit valuable highly migratory, straddling, and transboundary fishery resources beyond national jurisdiction and play an important role in international fisheries. Their management is complicated by shared-resource characteristics, multiple users, open-access conditions, and differing national interests. Major challenges include overfishing, bycatch, habitat impacts, illegal, unreported and unregulated fishing, weak governance, limited cooperation, and variable performance of Regional Fisheries Management Organizations (RFMOs). International frameworks, particularly the United Nations Convention on the Law of the Sea and the UN Fish Stocks Agreement, together with RFMOs, provide the foundation for conservation and management. Emerging approaches, including ecosystem-based management, improved monitoring and compliance, marine protected areas, and the Biodiversity Beyond National Jurisdiction framework, further strengthen sustainable ocean governance.

Introduction

High seas fisheries exploit fishery resources beyond national jurisdictions, outside the 200-nautical-mile Exclusive Economic Zones (EEZs) established under UNCLOS (United Nations, 1982; FAO, 1993). These waters support important transboundary and highly migratory fishery resources and are subject to an international legal and institutional framework for their conservation and management (Kaitala & Munro, 1993, 1997; United Nations, 1995). Fishing is mainly carried out by distant-water fleets using advanced technologies. However, overfishing, bycatch, habitat degradation, and illegal, unreported, and unregulated (IUU) fishing threaten the sustainability of these resources. Their management is coordinated through Regional Fisheries

Management Organizations (RFMOs) and international agreements such as UNCLOS and the UN Fish Stocks Agreement (UNFSA).

Historical Development

- **Before 1950:** Fisheries were largely concentrated in coastal waters, with relatively limited technological capacity for distant-water fishing.
- **1950s–1970s:** Industrial fleets expanded with developments in vessel capacity, refrigeration, processing, and fishing technology, increasing the ability to exploit distant and high seas resources (FAO, 1993).
- **1970s–1990s:** The adoption of UNCLOS in 1982 and the establishment of EEZs substantially changed the governance of marine fisheries, increasing the importance of international cooperation and RFMO-based management for high seas and shared stocks (FAO, 1993; United Nations, 1982; Kaitala & Munro, 1997).
- **2000–Present:** Fisheries governance has increasingly emphasized precautionary and ecosystem-based approaches, international cooperation, improved monitoring, and biodiversity conservation in areas beyond national jurisdiction.

Importance of High Seas Fisheries

High seas fisheries have ecological and economic importance because they exploit migratory and transboundary resources and are linked to international seafood markets. However, their direct contribution to global food security has been questioned, as a substantial proportion of high seas catches consists of high-value species traded internationally rather than fish directly supporting global food security (Schiller et al., 2018). International cooperation is therefore essential for balancing resource conservation, economic benefits, and equitable access to shared fish stocks (Munro, 1990; Kaitala & Lindroos, 1998).

Trends in High Seas Fisheries

High seas fisheries represent a relatively small proportion of total global marine capture fisheries and are dominated by highly migratory and commercially valuable species. Their development has been strongly influenced by the expansion of distant-water fishing fleets, technological advances, changes in international governance, and increasing conservation concerns (FAO, 2024; Schiller et al., 2018). Cooperation among fishing nations is particularly important because high seas fish stocks are shared resources and unilateral exploitation may

reduce the benefits available to all participants (Munro, 1990; Kaitala & Munro, 1993; Kaitala & Lindroos, 1998).

Major Fishery Resources of the High Seas

Major high seas fisheries target highly migratory, straddling, and other transboundary stocks, particularly tunas and other pelagic species. The international management of these resources is based largely on cooperation among states and RFMOs because the distribution of these stocks extends across national and international waters (United Nations, 1995; Kaitala & Munro, 1997).

Important resources include:

- **Tunas:** Major highly migratory fishery resources managed through international and regional cooperation (United Nations, 1995).
- **Billfishes:** Including marlins and swordfish, which are important highly migratory resources requiring international management.
- **Pelagic fishes and cephalopods:** Important components of distant-water and international fisheries (FAO, 2024).
- **Deep-sea fishes and crustaceans:** Resources that may be particularly vulnerable because of their biological characteristics and the potential impacts of intensive exploitation.

Major Fishing Gears Used in High Seas Fisheries

High seas fishing fleets employ a range of industrial gears, including longlines, purse seines, trawls, jigging systems, and other specialized fishing methods. The choice of gear depends on the target species and fishing area, while gear-related impacts such as bycatch and habitat disturbance require effective regulation and monitoring (FAO, 2024).

- **Trawling:** Highly efficient for certain fisheries but can raise concerns regarding impacts on vulnerable benthic habitats.
- **Longlining:** Commonly used to target highly migratory species, but interactions with non-target species, including seabirds, turtles, and sharks, are an important management concern.
- **Purse seining:** An important industrial method for catching schooling pelagic fishes.
- **Gillnets:** Can result in entanglement and bycatch of non-target species.
- **Jigging:** Widely associated with squid fisheries.
- **Pots and traps:** Used in selected crustacean and deep-water fisheries.

Key Technologies Supporting High Seas Fisheries

Modern high seas fisheries increasingly depend on vessel tracking, satellite-based monitoring, electronic reporting, and onboard technologies. Improved monitoring and information systems can strengthen fisheries management, transparency, compliance, and control of illegal activities (FAO, 2024). Important technologies include Vessel Monitoring Systems (VMS), Automatic Identification Systems (AIS), Remote Electronic Monitoring (REM), electronic logbooks, sonar and echo sounders, onboard refrigeration and processing systems, and other technologies supporting catch monitoring and traceability.

Issues in High Seas Fisheries

High seas fisheries face major governance and management challenges because resources occur across vast areas beyond national jurisdiction and are exploited by multiple states. The absence of effective cooperation can create incentives for overexploitation, while weaknesses in RFMO performance, scientific information, and enforcement can reduce management effectiveness (Munro, 1990; Kaitala & Munro, 1993)

Major issues include:

1. **Weak and fragmented governance:** The management of high seas biodiversity and fisheries involves multiple institutions and legal instruments, creating coordination challenges.
2. **Limited international cooperation:** Effective management requires cooperation among states sharing fish stocks (Munro, 1990; Kaitala & Lindroos, 1998).
3. **RFMO performance:** The effectiveness of RFMOs can vary depending on scientific capacity, decision-making, compliance, and enforcement.
4. **Overfishing and excessive fishing pressure:** Shared-resource fisheries can be vulnerable to overexploitation without effective collective management (Kaitala & Munro, 1993, 1997).
5. **Bycatch:** Non-target species may be affected by fishing operations, requiring appropriate management and mitigation.
6. **Habitat impacts:** Certain fishing activities may affect vulnerable marine ecosystems and habitats.
7. **IUU fishing and poor compliance:** Effective monitoring and enforcement are necessary to ensure that international and regional management measures are implemented.

8. **Economic inequality and access:** The costs and benefits of exploiting shared high seas resources may not be distributed equally among states, making cooperative arrangements important (Kaitala & Lindroos, 1998; Munro & Scott, 1985).

Management Measures for High Seas Fisheries

The sustainable management of high seas fisheries requires cooperation among states because fish stocks and fishing activities extend beyond the jurisdiction of individual countries. The principal legal framework includes UNCLOS and the UN Fish Stocks Agreement, while RFMOs play a central role in implementing regional conservation and management measures (United Nations, 1982, 1995; Kaitala & Munro, 1997).

Key management measures include:

1. **International cooperation:** Cooperation is essential for the management of shared and highly migratory fish stocks (Munro, 1990; Kaitala & Lindroos, 1998).
2. **RFMOs:** Regional organizations coordinate management measures for shared fish stocks.
3. **Catch and effort regulation:** Catch limits, quotas, and restrictions on fishing effort can help prevent overexploitation.
4. **Monitoring, control and surveillance:** Monitoring systems and compliance mechanisms are important for enforcing agreed management measures.
5. **Marine Protected Areas (MPAs):** High seas MPAs can contribute to biodiversity conservation, although their establishment and management present substantial legal and practical challenges (O'Leary et al., 2012; Sumaila et al., 2007).
6. **Precautionary and ecosystem-based approaches:** Fisheries management should consider ecosystems, habitats, and non-target species in addition to target stocks.
7. **Cooperative and rights-based approaches:** Economic and cooperative arrangements can help reduce competition and improve incentives for sustainable resource use (Munro & Scott, 1985; Kaitala & Lindroos, 1998).

Biodiversity Beyond National Jurisdiction (BBNJ) Agreement

The conservation and sustainable use of marine biodiversity beyond national jurisdiction has long been recognized as an important governance challenge because high seas ecosystems and resources fall outside the sovereignty of individual states. The BBNJ framework addresses major gaps in international ocean governance through measures relating to marine genetic

resources, area-based management tools, environmental impact assessments, and capacity building and technology transfer. The BBNJ framework is particularly relevant to the broader conservation of biodiversity in areas beyond national jurisdiction and complements the existing legal and institutional framework governing high seas fisheries.

Major Objectives and Focus Areas

The major areas addressed by the BBNJ framework include:

1. **Marine Genetic Resources (MGRs):** Addressing access and benefit-sharing.
2. **Area-Based Management Tools (ABMTs):** Supporting spatial measures, including marine protected areas, for biodiversity conservation.
3. **Environmental Impact Assessments (EIAs):** Assessing potential impacts of activities on the marine environment.
4. **Capacity Building and Technology Transfer:** Supporting developing states through scientific cooperation, training, and access to relevant technologies.

The importance of strengthened governance of biodiversity beyond national jurisdiction has been emphasized in earlier analyses of international marine governance (O'Leary et al., 2012).

Management of High Seas Fisheries and India

India's participation in high seas fisheries management is linked to its obligations under relevant international legal instruments and its participation in regional fisheries arrangements. Measures relating to authorization, monitoring, vessel reporting, compliance, and sustainable exploitation should be implemented in accordance with applicable national regulations and relevant international and regional conservation measures. The *Guidelines for Sustainable Harnessing of Fisheries in the High Seas by Indian-Flagged Fishing Vessels, 2025*, mandatates Letter of Authorization, VMS, AIS, digital logbooks, and other detailed Indian measures are not directly supported by the reference list currently provided. These statements should be supported with the relevant official Government of India notification, guideline, or fisheries authority document.

Future Directions for High Seas Fisheries

Future high seas fisheries management should focus on strengthening international cooperation, improving the effectiveness and accountability of RFMOs, and adopting ecosystem-based conservation and spatial management approaches. Enhanced scientific information, monitoring technologies, data sharing, and compliance systems will also be essential for

sustainable resource management. Furthermore, equitable participation and benefit-sharing among states can help reduce conflicts over shared and transboundary resources and promote long-term cooperation for the sustainable use of high seas fisheries (Munro, 1990; Kaitala & Lindroos, 1998)

Conclusion

High seas fisheries involve valuable shared and transboundary resources whose sustainable management depends fundamentally on international cooperation. The challenges associated with open-access conditions, multiple users, and differing national interests require effective legal frameworks, cooperative arrangements, and strong regional institutions (Munro, 1990; Kaitala & Munro, 1993, 1997). Strengthening cooperation, improving RFMO performance, protecting biodiversity, and developing effective monitoring and management systems will remain essential for the long-term sustainability of high seas resources (O'Leary et al., 2012; FAO, 2024).

References

FAO Fisheries Department. (1993). *Marine fisheries and the Law of the Sea: A decade of change*. Special chapter (revised) of *The State of Food and Agriculture 1992*. FAO Fisheries Circular No. 853. Rome: FAO.

Food and Agriculture Organization (FAO). (2024). *The State of World Fisheries and Aquaculture 2024*. Rome: FAO.

Kaitala, V., & Lindroos, M. (1998). Sharing the benefits of cooperation in high seas fisheries: A characteristic function game approach. *Natural Resource Modeling, 11*, 275–299.

Kaitala, V., & Munro, G. R. (1993). The management of high seas fisheries. *Marine Resource Economics, 8*, 313–329.

Kaitala, V., & Munro, G. R. (1997). The conservation and management of high seas fishery resources under the new law of the sea. *Natural Resource Modeling, 10*, 87–108.

Munro, G. R. (1990). The optimal management of transboundary fisheries: Game theoretic considerations. *Natural Resource Modeling, 4*, 403–426.

Munro, G. R. (1994). The management of high seas fishery resources. In *Proceedings of the 7th IIFET Conference*. Taipei.

Munro, G. R., & Scott, A. D. (1985). The economics of fisheries management. In A. V. Kneese & J. L. Sweeney (Eds.), *Handbook of Natural Resources and Energy Economics* (Vol. II, pp. 623–676). Amsterdam: North-Holland.

O'Leary, B. C., Brown, R. L., Johnson, D. E., von Nordheim, H., Ardron, J., Packeiser, T., & Roberts, C. M. (2012). The first network of marine protected areas (MPAs) in the high seas: The process, the challenges and where next. *Marine Policy, 36*(3), 598–605.

Schiller, L., Bailey, M., Jacquet, J., & Sala, E. (2018). High seas fisheries play a negligible role in addressing global food security. *Science Advances, 4*(8), eaat8351.

Sumaila, U. R., Zeller, D., Watson, R., Alder, J., & Pauly, D. (2007). Potential costs and benefits of marine reserves in the high seas. *Marine Ecology Progress Series, 345*, 305–310.

United Nations. (1982). *United Nations Convention on the Law of the Sea of 10 December 1982*. UN Doc. A/CONF.62/122.

United Nations. (1995). *Agreement for the implementation of the provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the conservation and management of straddling fish stocks and highly migratory fish stocks*. UN Doc. A/CONF.164/37.

United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks. (1995). *Agreement for the implementation of the provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the conservation and management of straddling fish stocks and highly migratory fish stocks*. Sixth Session, New York, 24 July–4 August 1995. United Nations, A/CONF.164/37, 8 September 1995.

Volume: 06 Issue No: 09

NATURAL FARMING: ECOLOGICAL PRINCIPLES AND SCIENTIFIC BASIS FOR SUSTAINABLE AGROECOSYSTEMS

Article ID: AG-VO6-I09-75

Dr. Prabhu Nayaka

Principal & Dean and I/c Registrar, Gujarat Natural Farming Science University,

Halol- 389350, Gujarat, India

Abstract

Natural farming represents an agroecological approach that emphasizes ecological balance, soil health, and minimal external inputs. Core principles—maintaining living roots, continuous soil cover, minimal soil disturbance, use of local bio-inputs, and reliance on natural ecological processes—are increasingly supported by scientific evidence. These practices enhance soil structure, biodiversity, nutrient cycling, and climate resilience. This article synthesizes current research on natural farming systems and evaluates their ecological and agronomic implications for sustainable agriculture.

Introduction

Modern intensive agriculture has led to soil degradation, biodiversity loss, and declining ecosystem services. In contrast, natural farming adopts principles aligned with ecological processes, aiming to restore soil health and system resilience. It shares conceptual foundations with regenerative agriculture, organic farming, and agroecology, focusing on biological interactions rather than synthetic inputs

Core Principles of Natural Farming

Maintaining Living Roots in the Soil

Continuous presence of living roots ensures active rhizosphere processes, where plant roots interact with soil microorganisms. Root exudates provide carbon substrates that stimulate microbial activity, enhancing nutrient cycling and soil aggregation.

Scientific evidence shows that systems maintaining living roots:

- Increase microbial biomass and diversity

- Improve soil carbon sequestration
- Enhance nutrient availability through symbiotic associations (e.g., mycorrhizae)

Living roots also reduce nutrient leaching and improve soil structure through biopore formation.

Continuous Soil Cover

Maintaining soil cover through crop residues, mulches, or cover crops protects soil from erosion, temperature fluctuations, and moisture loss.

Research indicates that:

- Soil cover significantly reduces wind and water erosion
- Enhances soil structural stability
- Improves water infiltration and retention

Additionally, decomposing organic residues contribute to soil organic matter and nutrient cycling, supporting long-term fertility.

Minimal Soil Disturbance

Minimal or zero tillage is a cornerstone of natural farming. Excessive tillage disrupts soil aggregates, microbial habitats, and carbon storage.

Empirical studies demonstrate that reduced disturbance:

- Enhances soil organic carbon and aggregation
- Improves water retention and drought resilience
- Increases microbial diversity and functional activity

Long-term no-till systems have shown regeneration of deep soil layers and improved nutrient dynamics.

Use of Local Bio-inputs

Natural farming promotes the use of locally available biological inputs such as:

- Farmyard manure
- Compost and vermicompost
- Botanical extracts (e.g., neem-based formulations)
- Indigenous microbial cultures

These inputs:

- Enhance microbial activity and soil enzymatic processes
- Improve nutrient mineralization
- Reduce dependency on synthetic fertilizers and pesticides

Field studies in India report improved soil quality indicators and microbial community shifts following the adoption of bio-input-based natural farming.

Reliance on Natural Ecological Processes

Natural farming systems depend on ecosystem services such as:

- Biological nitrogen fixation
- Natural pest regulation
- Pollination
- Nutrient recycling

Functional biodiversity plays a critical role in stabilizing agroecosystems. Diverse plant and microbial communities enhance productivity, resilience, and resistance to environmental stress Impacts on Soil Health and Ecosystem Functioning

Soil Organic Carbon and Fertility

Natural farming enhances soil organic carbon (SOC), a key indicator of soil health. Practices such as cover cropping, reduced tillage, and organic amendments contribute to carbon sequestration and improved fertility.

Soil Biodiversity

Soil organisms—including bacteria, fungi, earthworms, and arthropods—are central to nutrient cycling and soil structure formation. Natural farming promotes a biologically active soil system, often referred to as "living soil".

Water Dynamics and Climate Resilience

Improved soil structure and organic matter increase water-holding capacity, reducing vulnerability to drought and extreme weather events. This enhances resilience in rainfed and climate-stressed regions.

Agroecosystem Sustainability

Natural farming reduces environmental externalities such as:

- Chemical runoff
- Greenhouse gas emissions
- Soil degradation

It also improves long-term sustainability by lowering input costs and enhancing ecosystem services.

Evidence from Field Studies

Recent studies provide empirical validation of natural farming principles:

- **India (Madhya Pradesh):** Transition to natural farming improved soil quality and microbial community structure even in early stages
- **Permaculture systems (UK):** Increased soil carbon stocks, microbial abundance, and nutrient availability compared to conventional farming
- **No-tillage systems (China):** Significant improvements in deep soil health, water retention, and biodiversity after long-term adoption

Challenges and Limitations

Despite its benefits, natural farming faces several challenges:

- Initial yield variability during transition
- Knowledge-intensive management
- Limited large-scale mechanization compatibility
- Need for region-specific adaptations

However, long-term benefits often outweigh short-term constraints.

Future Perspectives

Integration of traditional knowledge with modern science can enhance the scalability of natural farming. Emerging areas include:

- Microbial inoculants and biofertilizers
- Climate-smart agroecological practices
- Carbon farming and ecosystem service valuation

Conclusion

Natural farming offers a scientifically grounded pathway toward sustainable agriculture by aligning farming practices with ecological processes. Its principles—living roots, soil cover, minimal disturbance, bio-inputs, and ecological reliance—collectively enhance soil health, biodiversity, and resilience. As global agriculture faces increasing environmental challenges, natural farming presents a viable and scalable solution for regenerative and sustainable food systems.

References

1. Panday, D. et al. (2024). Organic farming and sustainable agroecosystems. *Sustainability*.
2. Singh, A.P. et al. (2024). Natural farming: Cultivating harmony with nature.

3. Williamson, R.F. et al. (2024). Permaculture and soil carbon dynamics. *Agronomy*.
4. Environmental Indicators (2025). Soil quality in natural farming systems (India).
5. Zhang et al. (2022). No-tillage and soil regeneration. *Science of the Total Environment*.
6. Frontiers in Sustainable Food Systems (2023). Continuous living cover and agroecology.
7. Regenerative agriculture and soil health (2025).
8. Noble Research Institute (2023). Soil biological activity and structure

Volume: 06 Issue No: 09

DETECT EARLY, PROTECT MORE: ARTIFICIAL INTELLIGENCE FOR EARLY DISEASE SYMPTOM DETECTION IN PULSE CROPS

Article ID: AG-V06-I09-76

Akash Bharti[1,2], Chandan Kumar Deb[2*], Madhurima Das[3], MD. Ashraful Haque[2], Alka Arora[3], Devraj Mishra[4], Rishikesh Kumar[4], Anup Chandra[4]

[1] Graduate School, ICAR-Indian Agricultural Research Institute, New Delhi-110012, India

[2] ICAR-Indian Agricultural Statistics Research Institute, New Delhi-110012, India

[3] ICAR-Indian Agricultural Research Institute, New Delhi-110012, India

[4] ICAR-Indian Institute of Pulses Research, Kanpur-208024, India

*Corresponding Author: Chandan Kumar Deb

Abstract

Pulse crops are central to nutrition, soil health and farm livelihoods, yet diseases can reduce their productivity and quality. The greatest opportunity for crop protection often comes when symptoms are still small and localized, but these early changes are also the easiest to miss or confuse with nutrient stress, ageing or environmental injury. Artificial Intelligence (AI) can strengthen field scouting by examining colour, texture, shape and spatial patterns in plant images consistently and at scale. This article explains why early visible symptom detection matters, how image-based Artificial Intelligence can support it, and what is required for reliable use under field conditions. A case study in urdbean illustrates a healthy-reference approach in which the system first asks whether a leaf still looks normal before attempting to identify the disease. Such approaches can complement expert diagnosis and support faster crop-health decisions.

Keywords: Artificial Intelligence; computer vision; early disease detection; pulse crops; plant health; urdbean

1. Introduction

Pulse crops such as chickpea, pigeonpea, lentil, mungbean and urdbean are valued for plant protein, dietary diversity and their role in nitrogen-fixing cropping systems. They are also exposed to a wide range of biotic and abiotic constraints. Reviews of mungbean production have

shown that diseases, insect pests and environmental stresses together remain major barriers to stable productivity.[1]

For a farmer, however, the practical question is not only "What disease is this?" but also "How early can I notice that something is going wrong?" Many foliar diseases begin with faint yellowing, tiny lesions, slight puckering or weak changes in leaf texture. At this stage, the affected area may be only a small fraction of the leaf. If the change is noticed early, the field can be inspected more closely, suspicious plants can be monitored, and appropriate crop-protection or expert-advisory decisions can be taken sooner.

This is where Artificial Intelligence (AI) can add value. Image-based AI does not replace plant pathology; rather, it can provide a rapid and repeatable screening layer. A smartphone or camera can capture plant images, and an AI model can examine visual cues that may be difficult to evaluate consistently across hundreds or thousands of plants. Deep-learning studies have already demonstrated the ability of computer vision to learn disease-related patterns directly from images, although performance usually falls when conditions become more complex than the training data.[2,3]

2. Why the first symptoms matter?

Disease development is a process, not a single event. An advanced symptom is often the final visible expression of changes that started much earlier. In Yellow Mosaic Disease of urdbean, for example, small chlorotic areas can expand into the familiar yellow-green mosaic. In leaf crinkle, slight changes in surface texture or leaf form can become pronounced puckering, curling and deformation. The earlier visible stage therefore represents a valuable window for surveillance, even when an exact diagnosis is still uncertain.

Early recognition is especially important for diseases that can spread rapidly within or between fields, or when management is more useful before a large proportion of the crop becomes affected. The practical objective is therefore early warning: identify a suspicious plant or leaf while the abnormality is still limited, then support a timely decision about closer inspection, diagnosis or management.

3. Why early symptoms are easy to miss?

The same feature that makes early detection valuable also makes it difficult: early symptoms are weak. A faint yellow patch may resemble nutrient deficiency or natural ageing. A slight change in leaf texture may be confused with heat, water stress, insect feeding or physical

damage. Sunlight, shadows, soil background, leaf overlap and camera angle add further variation. Two healthy plants may also differ naturally because of genotype, age or growing conditions.

For an AI system, this means that a "disease image" is not a fixed visual object. Disease severity changes continuously, while most datasets use simple labels such as healthy, early and advanced. Reliable early detection therefore requires diverse images, careful labelling, independent testing and special attention to the early stage rather than relying only on overall accuracy.

4. How AI can help: from an image to an early warning?

Modern computer vision can support several steps in disease screening. A segmentation model can first isolate the leaf from soil, sky and neighbouring vegetation. U-Net is a widely used example of a deep-learning architecture designed for pixel-level segmentation and has become influential across image-analysis applications.[4]

A second model can then analyse the leaf itself. Convolutional neural networks learn combinations of colour, edges, texture, shape and spatial arrangement directly from training images. In conventional disease classification, the model is trained to select one label from a fixed set of known classes. This is useful when symptoms are well developed and the possible diseases are known.

Early screening creates a harder problem because the leaf may not yet look like a textbook disease example. An alternative is anomaly detection: instead of asking the system to memorize every possible disease, train it to learn the normal appearance of healthy leaves and flag samples that depart strongly from that healthy pattern. Deep one-class learning provides one computational foundation for this "learn normal first" strategy.[5]

5. Early visible is not the same as pre-symptomatic

The phrase "early detection" needs careful use. With ordinary red-green-blue photographs, AI can detect subtle visual symptoms that a person may overlook, but this does not automatically prove that infection was identified before symptoms existed. True pre-symptomatic detection requires evidence that the pathogen or physiological disturbance was present before visible expression. Sensors such as hyperspectral imaging can sometimes capture biochemical or physiological changes earlier than standard photographs; such approaches have been explored for early plant viral disease detection.[6]

For general field use, it is therefore safer to describe camera-based systems as tools for early visible symptom recognition unless the experimental design specifically demonstrates pre-symptomatic detection.

6. What will make AI useful in farmers' fields?

A useful system must do more than score well on a laboratory test set. It should be trained and evaluated across cultivars, growth stages, locations, seasons, lighting conditions and camera devices. Images from the same plant should not be scattered across training and testing sets, because this can make the model appear more accurate than it truly is. Performance on early symptoms should be reported separately, and the system should be able to mark uncertain or unfamiliar cases for expert review rather than forcing every image into a known disease class.

Deployment also matters. Large models may perform well on workstations but be inconvenient for phones or field devices. Lightweight models, edge computing and clear user interfaces can make screening faster and more practical. The most useful output is not simply a disease name; it is a decision-support message such as "this leaf appears abnormal - inspect this plant and nearby plants more closely."

7. Case study: a "healthy-first" direction for urdbean

A recent urdbean case study explored a different way to organize the AI decision. Instead of immediately asking a classifier to choose among healthy, Yellow Mosaic Disease and Urdbean Leaf Crinkle Disease, the system first asked a simpler question: "Does this leaf still look like the healthy reference?" This is important for early symptoms because a weak abnormality may be easier to recognize as a departure from normal than as a fully developed disease pattern.

The workflow first isolated the leaf using U-Net. A Healthy Representation Anomaly Detector then learned the feature pattern of healthy leaves. It combined two signals: how poorly a healthy-trained model could reconstruct the new sample, and how far the sample lay from the normal healthy feature distribution. Only leaves that crossed a calibrated anomaly threshold were sent to a lightweight disease classifier for disease identity. In an independent test, the approach detected about 92 of every 100 diseased leaves while correctly recognizing about 90 of every 100 healthy leaves; all early Yellow Mosaic Disease images in that test were flagged as abnormal. The result does not establish pre-symptomatic infection detection, but it demonstrates the potential of healthy-reference modelling as an early visible screening strategy.

The broader lesson is that future crop-health AI may benefit from separating two tasks: first notice that something is unusual, and only then decide what the problem is. This design is attractive when field images may contain new diseases, nutrient stress, insect injury or other abnormalities that were not represented during training.

Conclusion

The real promise of AI in plant disease management is not merely to recognize an obvious disease faster. Its greater value may be in helping farmers and crop professionals notice the first meaningful visual change early enough to act. In pulse crops, those first symptoms can be small, inconsistent and easily confused with other stresses, making large-scale visual scouting difficult to standardize.

Computer vision, deep learning, segmentation and anomaly detection can provide a rapid and repeatable screening layer. Their success, however, depends on representative field data, careful validation, transparent uncertainty and realistic claims about what the sensor can observe. Healthy-reference modelling offers one promising direction because it allows the system to ask whether a plant has departed from normal before trying to name the disease. Used in this way, AI can complement - not replace - farmers, extension workers and plant pathologists by making crop-health surveillance earlier, more focused and more scalable.

References

Nair RM, Pandey AK, War AR, Rao BH, Shwe T, Alam A et al. 2019. Biotic and abiotic constraints in mungbean production - progress in genetic improvement. Front. Plant Sci. 10: 1340.

Ferentinos KP. 2018. Deep learning models for plant disease detection and diagnosis. Comput. Electron. Agric. 145: 311-318.

Ronneberger O, Fischer P, Brox T. 2015. U-Net: Convolutional networks for biomedical image segmentation. In: Medical Image Computing and Computer-Assisted Intervention - MICCAI 2015. Springer, Cham, pp. 234-241.

Ruff L, Vandermeulen R, Görnitz N, Deecke L, Siddiqui SA, Binder A et al. 2018. Deep one-class classification. Proc. 35th Int. Conf. Mach. Learn. 80: 4393-4402.

Nguyen C, Sagan V, Maimaitiyiming M, Maimaitijiang M, Bhadra S, Kwasniewski MT. 2021. Early detection of plant viral disease using hyperspectral imaging and deep learning. Sensors 21(3): 742.

Volume: 06 Issue No: 09

MICROBES AS NANO-FARMERS: HOW TINY ORGANISMS ARE BUILDING THE FERTILIZERS OF TOMORROW

Article ID: AG-VO6-I09-77

Gopika J

Centre for Agricultural Nanotechnology, Tamil Nadu Agricultural University

Coimbatore 641003, Tamil Nadu, India

Introduction

Walk through any farming region today and you will hear the same worry repeated in different accents: soils are tired, fertilizer costs keep climbing, and the nutrients farmers do apply often never reach the plant at all. Studies on conventional nitrogen and phosphorus fertilizers suggest that a large share of what is spread on a field is lost — washed away by rain, locked up in the soil, or broken down before roots can absorb it. That waste is not just an economic problem. Runoff nutrients feed algal blooms in rivers and lakes, and the manufacture of synthetic fertilizer is itself an energy-intensive, carbon-heavy business.

Nanotechnology has been offered as one way out of this bind. Nutrients packaged as nanoparticles — particles roughly a billionth of a metre across — can be designed to release slowly, stick to root surfaces, or slip through tiny pores in leaves and cell walls that ordinary fertilizer granules simply cannot enter. But there is a catch: many of the standard ways of manufacturing nanoparticles rely on toxic solvents, strong acids, or heavy energy input, which rather defeats the purpose of making agriculture greener. This is where microbes step in. Bacteria, fungi, yeasts, and algae have spent billions of years perfecting the art of building precise structures at the molecular scale, and scientists have learned to borrow that talent. The result is a growing field known as microbe-mediated nanofertilizer production — using living microorganisms as tiny, self-replicating factories that assemble nutrient-carrying nanoparticles cheaply, safely, and with far less environmental baggage than conventional chemistry.

What Exactly Is a Microbe-Mediated Nanofertilizer?

A nanofertilizer is simply a fertilizer in which the active nutrient — nitrogen, phosphorus, potassium, zinc, iron, or another element the plant needs — is delivered inside or attached to a nanoscale carrier rather than as a loose salt or granule. The 'microbe-mediated' part refers to how that nanoparticle is made. Instead of using chemical reducing agents in a laboratory reactor, researchers feed a metal salt solution — say, silver nitrate or zinc acetate — to a culture of bacteria, fungi, or algae. Proteins, enzymes, and other biomolecules produced by the microorganism grab the metal ions and convert them into solid nanoparticles, a process often called 'green synthesis' or biosynthesis.

This can happen in two broad ways. In intracellular synthesis, the microbe absorbs metal ions into its own cells and nanoparticles form inside the cell membrane, which then have to be extracted afterward. In extracellular synthesis, the microorganism secretes enzymes — such as nitrate reductase in certain fungi and bacteria — directly into the surrounding liquid, and the nanoparticles form outside the cell in the culture broth. Extracellular synthesis is generally easier to scale up commercially because the particles do not need to be pried out of living tissue.

The Microbial Cast of Characters

A surprisingly wide range of organisms has proven capable of this kind of nanoparticle 'manufacturing.' Bacteria such as Bacillus, Pseudomonas, and various strains of Escherichia have been used to produce silver, zinc oxide, and iron oxide nanoparticles. Fungi, including species of Aspergillus, Trichoderma, and Fusarium, are popular because they secrete large quantities of extracellular enzymes, making downstream purification simpler. Yeasts and microalgae have also entered the picture, valued for their fast growth and, in the case of algae, an added ability to fix carbon dioxide while they work.

Many of the microbes used are not random choices; they are the same plant-growth-promoting organisms — nitrogen fixers, phosphate solubilizers, and biocontrol fungi — that agronomists already value for healthy soil. That overlap is one of the more elegant aspects of the field: a single microbial strain can, in principle, both manufacture a nanofertilizer and continue living in the soil as a beneficial partner to the crop, solubilizing nutrients and suppressing disease long after the initial nanoparticle has done its job.

Why Plants Respond So Well to Nano-Sized Nutrients

The appeal of nanoscale delivery comes down to surface area and size. A gram of material broken into nanoparticles exposes vastly more surface area than the same gram in a coarse granule, so nutrients bind and release more efficiently. Because the particles are so small, many can be taken up directly through stomatal pores on leaves or through the fine channels in root cell walls, bypassing some of the soil-based losses — leaching, fixation by clay minerals, and microbial immobilization — that plague conventional fertilizers.

Several nanofertilizers are also engineered to be 'smart,' releasing their nutrient payload gradually over weeks rather than dumping it all at once. Zinc oxide and iron oxide nanoparticles, in particular, have shown promise in correcting micronutrient deficiencies that are notoriously hard to fix with ordinary fertilizer, because those elements tend to bind tightly to soil particles before roots can use them.

Benefits Beyond the Nutrient Itself

The advantages of the microbial route go beyond just making nanoparticles cheaply. Because the synthesis happens in water, at mild temperatures, and without harsh chemical reagents, the resulting nanoparticles tend to be less toxic to soil life and to the humans handling them. The biomolecules that microbes use to build the particles often remain attached as a thin organic coating, which can improve how well the particles are tolerated by plant tissue and how stable they remain in storage.

There is also a cost argument. Culturing bacteria or fungi in a tank of nutrient broth is, in relative terms, inexpensive and easy to scale compared with running chemical reactors that need controlled temperatures, pressures, and hazardous-waste disposal. For smallholder farmers and developing agricultural economies, that difference matters.

The Challenges That Remain

None of this is quite ready to replace the fertilizer bag in every farmer's shed just yet. Producing nanoparticles at laboratory scale, in a flask, is very different from producing tonnes of consistent, well-characterized material for a national fertilizer market. Batch-to-batch variation in particle size and shape is a persistent problem when biology, rather than a tightly controlled chemical reaction, is doing the building.

Regulatory frameworks for nanomaterials in agriculture are also still catching up, particularly around long-term questions: what happens when nanoparticles accumulate in soil

over repeated growing seasons, and how do they move through food chains? Researchers are actively studying the ecotoxicology of these materials, but robust, long-term field data — as opposed to short greenhouse trials — remain relatively scarce. Cost of downstream purification, especially for intracellularly produced particles that must be extracted from cells, is another bottleneck that keeps many promising strains confined to the laboratory.

Where the Field Is Headed

Despite these hurdles, momentum is building. Researchers are experimenting with combining nanofertilizers directly with living plant-growth-promoting microbes in a single product, creating a kind of hybrid biofertilizer that delivers both a nutrient boost and an ongoing microbial partnership in the root zone. Others are exploring nanoparticles engineered from agricultural waste-derived microbial cultures, closing the loop between farm byproducts and farm inputs. As genetic and metabolic engineering tools make it easier to fine-tune which enzymes a microbe secretes, the size, shape, and release behaviour of these nanoparticles should become far more predictable and controllable than they are today.

Conclusion

Microbe-mediated nanofertilizers sit at an appealing intersection of biology, chemistry, and sustainable agriculture. By recruiting bacteria, fungi, and algae as low-cost, low-toxicity nanoparticle factories, researchers are working toward fertilizers that deliver nutrients more precisely, waste less, and leave a lighter environmental footprint than the fertilizers most farms rely on today. The science is still maturing — scale-up, consistency, and long-term safety data all need more work — but the direction is clear. In trying to feed a growing population without further straining soils and waterways, some of the most useful allies may turn out to be organisms too small to see.

References

Basit, F., Wang, H., Deepak, V., Nie, J., Wang, Q., Sulieman, S., El-Keblawy, A., Mohamed, Z. E. A., & Sheteiwy, M. S. (2026). Microbe-mediated nanotechnology for heavy metal detoxification and crop resilience: mechanisms, advances, and future prospects. Frontiers in Microbiology.

Devra, V., et al. Biogenic Synthesis of Zinc Nanoparticles, Their Applications, and Toxicity Prospects. Frontiers in Microbiology, 13:824427.

Encyclopedia.pub. Biogenic Synthesis of Nanomaterials as Nanofertilizers. Entry summarizing microbe-mediated intracellular and extracellular nanoparticle synthesis routes.

Palmgren, M. G., et al. (2008). Zinc biofortification of cereals: problems and solutions. Trends in Plant Science.

Jameel, M. S., et al. (2020). Green synthesis of zinc oxide nanoparticles and their applications: a review. Nanotechnology Reviews.



Volume: 06 Issue No: 09

UNMANNED AERIAL VEHICLES (UAVS) : A NEW ERA OF PRECISION FARMING AND SUSTAINABLE AGRICULTURE

Article ID: AG-V06-I09-78

Vipin Tanwar*[1], Gagandeep Kaur[2] and Manpreet Kaur[3]

[1]Research Scholar, Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, Jammu and Kashmir (India) - 180009

[2]Research Scholar, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, Punjab (India) - 141004

[3]Research Scholar, Department of Agriculture, Mata Gujri College, Sri Fatehgarh Sahib, Punjab (India) - 140406

*Corresponding author: Vipin Tanwar

Abstract

Agricultural Drones, also known as Unmanned Aerial Vechicles (UAVs) are the most important and emerging technology for precision agriculture by providing rapid, high-resolution field information and supporting timely farm operations. These are of various types including multirotor, fixed wing and hybrid drones which are equipped with advanced cameras, sensors, navigation systems and application equipment. Their major application consists of monitoring crops, pest and weeds detection, evaluate nutrient and water variability and perform targeted spraying. They are expected to become increase autonomous in the future through integration with artificial intelligence, machine learning, robotics, Internet of Things and digital farm-management systems. Overall, Agricultural Drones represent a promising technology for improving precision, resource-use efficiency, productivity and sustainability in the modern agricultural production systems.

Keywords: Artificial intelligence, Internet of things, Precision agriculture, Robotics and Sensors

Introduction

Agriculture forms the backbone of food security, rural livelihoods, and economic development across the world. With the global population projected to exceed 9.7 billion by

2050, agricultural production must increase substantially while simultaneously addressing constraints such as declining natural resources, labour shortages, excess chemical application, environmental degradation, and increasing production costs. To combat such issues, agriculture is rapidly adopting digital technologies to improve productivity, resource-use efficiency and sustainability. In this purpose, Agricultural Drones which are also called Unmanned Aerial Vehicles (UAVs), have emerged as promising tools for obtaining high-resolution information at field scale and helpful in performing the field operations. Their ability to fly at low altitude and collect imagery data at flexible intervals makes them particularly useful for crop monitoring, field mapping and precision management (Zhang and Kovacs, 2012). Also, the modern agricultural drones can carry RGB, multispectral, thermal and hyperspectral imaging along with LiDAR sensors to collect information about crop condition, canopy structure and field variability.

They acquired images which can be processed into orthomosaic maps, vegetation indices and other spatial products that assist in identifying crop stress, weeds, nutrient variability, pest and disease hotspots and irrigation problems. The repeated flights of drone can provide information on changes in crop growth during different stages, supporting timely field scouting and management decisions (Tsouros *et al.*, 2019). Apart from monitoring, they are increasingly being used for agricultural operations, particularly precision spraying by applying herbicides, insecticides, fungicides and foliar inputs under controlled application systems and relatively low carrier volumes. They can also be useful in wet fields or standing crops where conventional machinery may cause soil compaction or crop damage. However, application effectiveness depends on correct calibration, nozzle selection, flight speed, operating height and suitable weather conditions (Puri *et al.*, 2017). The integration of drones with Geographic Information Systems (GIS), Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT) sensors and digital farm-management platforms is further expanding their potential for effective field operations. In the future, these are expected to provide more autonomous flight, automated image interpretation and site-specific management. Therefore, agricultural drone are emerged as sustainable and resource efficient technology for modern precision agriculture.

Major Components of Agricultural Drones

- **Airframe:** This provides the structural framework and determines stability, strength, weight and payload capacity.

- **Motors and propellers:** This generate thrust for take-off, hovering, forward movement and landing.
- **Battery and power system:** This supplies energy to propulsion, sensors, communication and spraying equipment and largely determines flight duration.
- **Flight controller:** It helps in maintains stability and controls flight using information from gyroscopes, accelerometers, compass and positioning systems.
- **Navigation system:** This integrates with GPS/GNSS and RTK systems provide positioning, waypoint navigation, mapping and repeatable field operations.
- **Sensors and cameras:** It helps in making images by RGB, multispectral, thermal and hyperspectral images by intergration with LiDAR sensors provide crop and field information.
- **Spraying system:** It includes tank, pump, filters, pipes, flow-control units and nozzles for application of agricultural inputs.
- **Communication system:** This connects the drone with the operator or ground-control station for mission planning and monitoring.
- **Data-processing system:** This converts aerial images into orthomosaics, vegetation indices, maps and other useful information.
- **Safety system:** It includes obstacle detection, geofencing, return-to-home, low-battery alerts and emergency functions.

Working principle of Agricultural Drones

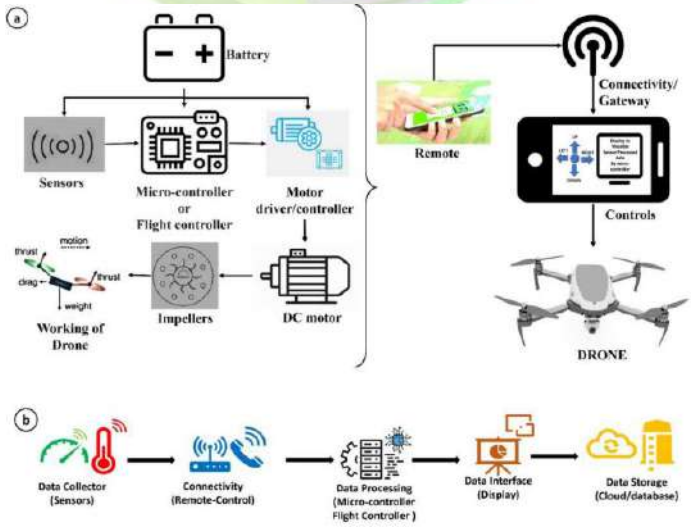


Fig.1. Flow diagram of working principle of agricultural drones (Makam *et al.*, 2024)

They are mainly operated remotely by a train operator or through pre-planned automated flight paths using GPS/GNSS and RTK technology. The flight-control system guides the drone along the planned route while onboard sensors and cameras collect field data. In spraying operations, pumps and nozzle deliver agricultural inputs at a controlled rate. This enables timely and precise field monitoring and input application.

Types of Agricultural Drones

1.Multirotor Drones

They use the several rotors to generate lift and can take off, land and hover vertically. Their high manoeuvrability makes them suitable for crop monitoring, mapping and spraying. These operate at low altitude and maintain controlled flight over specific field areas. However, their flight endurance is generally lower than fixed-wing platforms, particularly with heavy payloads. They are especially useful for small and medium-scale agricultural operations.

2.Fixed-Wing Drones

They can generate lift through wings and generally provide longer flight endurance and greater area coverage. These are particularly suitable for large-scale field mapping, crop monitoring and remote sensing. Unlike multirotor drones, they generally cannot hover at a fixed position. They may also require suitable space or specialized systems for take-off and landing. Their greater endurance makes them useful for surveying large agricultural landscapes.

3.Hybrid VTOL Drones

These are mainly combine the vertical take-off landing (VTOL) capability of multirotor platforms with the efficient forward flight of fixed-wing aircraft. They can operate without conventional runways while providing greater endurance and coverage. There features make them suitable for large-area mapping and monitoring. However, their design and control systems are more complex, resulting in higher technical and maintenance requirements.

4. Imaging Drones

These are designed primarily for collecting aerial information using cameras and remote-sensing instruments. They may carry RGB, multispectral, thermal, hyperspectral or LiDAR sensors depending on the purpose of the survey. They are used for crop monitoring, plant counting, stress detection, weed mapping and field characterization. Their performance depends on sensor quality, flight planning, environmental conditions and image-processing methods.

5. Spraying Drones

These are equipped with tanks, pumps, flow-control systems and nozzles for applying agricultural chemicals and foliar inputs. Their work at low-altitude operation can be useful in wet fields and standing crops where ground machinery is difficult to operate. Also, their application performance depends on flight speed, height, nozzle type, droplet size, flow rate and wind conditions. The proper calibration and responsible chemical handling are essential for effective and safe operation.



Fig. 2. Major types of Agricultural drones (Spackman, 2023)

Applications of Agricultural Drones

1. Crop Monitoring

They are providing high-resolution images for monitoring crop establishment, canopy development, plant density and spatial variability. Their repeated flights can track crop growth throughout the season and identify areas requiring detailed ground inspection. The multispectral and thermal sensors can provide additional information about crop stress that may not be visible in ordinary images. This drone-based monitoring is therefore supports timely and site-specific crop-management decisions (Tsouros *et al.*, 2019).

2. Weed Detection

The high-resolution drone imagery can distinguish crop plants, weeds and soil surfaces which is used to develop weed distribution maps. The RGB and multispectral sensors, combined

with image processing and machine-learning techniques, can improve weed identification. These maps can support targeted herbicide application and reduce unnecessary treatment of weed-free areas. This approach is particularly useful where weeds occur in patches rather than uniformly across the field (Pérez-Ortiz *et al.*, 2016).

3. Pest and Disease Detection

These can identify crop areas showing symptoms associated with pest infestation or disease development. The changes in canopy colour, structure and spectral response can indicate stressed areas requiring further field inspection. Also, thermal and multispectral sensors can provide additional information for identifying crop stress. The drone-based surveillance can therefore help prioritize field scouting and support timely management. However, ground verification remains important because different stresses can produce similar visual or spectral responses (Mahlein, 2016).

4. Nutrient Assessment

The drone imagery can identify spatial differences in crop vigour that may be associated with nutrient variability. As multispectral and hyperspectral sensors can provide reflectance information and vegetation indices related to crop condition. When these maps are combined with soil testing and field observations, they help in identify areas requiring further nutrient assessment. Such information can contribute to site-specific nutrient management and more efficient fertilizer use.

5. Irrigation Management

The thermal and multispectral drone imagery can help identify spatial differences associated with crop water stress. As areas with elevated canopy temperature or altered spectral responses may indicate inadequate water availability or irrigation problems. The high-resolution maps can identify dry zones requiring further investigation. The combining drone observations with soil-moisture sensors and weather information can improve irrigation scheduling and contribute to efficient agricultural water management.

6. Precision Spraying

These are used to apply the herbicides, insecticides, fungicides and foliar nutrients along predefined flight paths using controlled application rates through their nozzles. They can be useful where conventional machinery cannot easily operate, particularly in wet fields or standing crops. The proper calibration of flow rate, nozzle type, droplet size, flight speed and height is

essential for uniform application. The weather conditions must also be considered to minimize spray drift and improve deposition efficiency (Puri *et al.,* 2017).

7. Field Mapping

These are rapidly produce high-resolution agricultural maps using overlapping aerial images and accurate positioning systems. The photogrammetric processing can generate orthomosaics, surface models, field boundaries and other spatial products. Such information can support crop planning, drainage assessment, experimental research and identification of within-field variability. As repeated mapping can also document changes in field conditions over time, making them valuable tools for agricultural surveying and digital farm management.

8. Crop Phenotyping and Research

These are providing rapid and non-destructive assessment of crop characteristics in research fields. They can measure or estimate canopy cover, plant height, biomass-related traits, stress responses and treatment differences. The repeated observations can supplement conventional field measurements while providing detailed spatial information. As integration with AI and statistical analysis can support high-throughput crop phenotyping and improve understanding of crop responses to management practices.



Fig.2. Major application of Agricultural drones (Bahera *et al.*, 2024)

Future Prospects of Agricultural Drones

1. AI and Machine Learning Integration: The integration of artificial intelligence (AI) and machine learning (ML) will make agricultural drones more intelligent and autonomous. As

advanced algorithms can analyse aerial images to identify weeds, diseases, nutrient deficiencies and crop stress. This AI-based systems can detect subtle changes that may not be easily visible through conventional field scouting. This machine learning models can also classify crop conditions and generate field-specific management recommendations which will improve the accuracy and speed of agricultural decision-making. The integration with historical field data can further improve prediction and early-warning capabilities.

2. Autonomous Drone Operations: The advancement in this technology are expected to perform flight planning, navigation and field monitoring with minimal human intervention. As autonomous systems will use GPS/GNSS, sensors and intelligent navigation technologies for precise movement across fields. The obstacle detection and avoidance systems will improve operational safety. Along with this, the automated take-off, landing and return-to-home functions can simplify routine field operations. Such capabilities will allow repeated monitoring at critical crop growth stages. This autonomous operation can also improve labour efficiency and reduce the time required for large-scale field surveys.

3. Advanced Sensor Technologies: The development of lightweight and high-resolution sensors will expand the capabilities of this technology. The multispectral and hyperspectral sensors can provide detailed information about crop health and physiological variability whereas the thermal sensors can assist in detecting water stress and variations in crop temperature. The LiDAR technology can provide information on crop structure, plant height and canopy characteristics. This help in combining different sensors can provide a more comprehensive assessment of crop and field conditions. These advancements will support earlier detection and more precise crop management.

4. Integration with IoT and Digital Farming: The agricultural drones will increasingly operate in the future as part of interconnected digital farming systems. There observations can be combined with information from soil-moisture sensors, weather stations and other IoT devices. This integration can provide real-time information on crop, soil and environmental conditions. As drone-generated data can also be linked with satellite imagery and farm-management platforms. Such systems will support site-specific irrigation, fertilization and crop-protection decisions. The combination of multiple data sources can improve resource-use efficiency and overall farm management.

5. Drone Swarms and Collaborative Operations: The development of coordinated drone-swarm technology may enable multiple drones to work simultaneously over large agricultural areas. As different drones could perform complementary tasks such as monitoring, mapping and crop protection. The coordinated operations could increase field coverage and reduce the time required for large-scale activities. As swarm-based systems may be particularly useful during time-sensitive operations such as pest surveillance and crop protection. The Intelligent communication between different drones can help maintain coordinated flight paths and avoid collisions. This technology could significantly expand the scale and efficiency of future agricultural drone operations.

6. Smart and Sustainable Farm Management: The drones will increasingly become part of integrated decision-support and farm-management systems. The drone-derived maps can help identify spatial variability and guide site-specific application of agricultural inputs. This can improve the efficiency of water, fertilizers and crop-protection chemicals. There integration with GIS, AI, satellite data and farm records can support more accurate management decisions. As reduced input wastage can contribute to lower production costs and improved environmental sustainability.

Key Benefits and Challenges in Agricultural Drones

Benefits	Challenges
Rapid and timely field monitoring	High initial investment
Precision application of agricultural inputs	Limited battery endurance
Reduces labour requirement	Weather and wind sensititvity
Saves times and water reuirement	Limited payload capacity
Site-specific crop management	Skilled operators are required
Provides high resolution field data	Maintenance and Technical support
Detect weeds, pests and diseases early	Connectivity limitations in some areas

Conclusion

The Agricultural Drones are rapidly becoming valuable tools for precision and digital agriculture, providing efficient solutions for crop monitoring, field mapping, stress detection and precision spraying. With the advancement in future technology of artifical intelligence, autonomous systems and sensors, their role is expected to expand further in farming operations.

Thus, effective integration of agricultural drones with modern farm-management systems can contribute to more efficient, precise and sustainable agricultural production.

References

1. Bahera K., Babbar B., Vyshnavi R.G., Yankanchi S., Verma B., Patel T. et al. 2024. Intelligent technologies and their trasnformative role in modern agriculture: a comparative approach. Enivron. Conser. Jour. 25(3): 870-880.
2. Mahlein A.K. 2016. Plant disease detection by imaging sensors – parallels and specific demands for precision agriculture and plant phenotyping. Plant Dis. 100: 241–251.
3. Makam S., Komatineni B.K., Meena S., Meena U. 2024. Unmanned aerial vechicles (UAVs): an adoptable technology for precision and smart farming. Disco. Inter. Thing. 4: 12.
4. Pádua L., Marques P., Adão T., Guimarães N., Sousa A., Peres E. et al. 2020. Vineyard variability analysis through UAV-based RGB imagery. Remote Sen. 12: 2192.
5. Pérez-Ortiz M., Peña J.M., Gutiérrez P.A., Torres-Sánchez J., Hervás-Martínez C., López-Granados F. 2016. A semi-supervised system of multi-class classification for weed mapping in precision agriculture. PLoS one. 11: e0160064.
6. Puri V., Nayyar A., Raja L. 2017. Agriculture drones: A modern breakthrough in precision agriculture. Jour. Stati. and Manage. Sys. 20: 507–518.
7. Spackman, C. 2023. Considerations for drone use on a ranch (Guide B-828). New mexico State University, College of Agricultural Consumers and Environmental Sciences.
8. Tsouros D.C., Bibi S., Sarigiannidis P.G. 2019. A review on UAV-based applications for precision agriculture. Inform. 10: 349.
9. Zhang C., Kovacs J.M. 2012. The application of small unmanned aerial systems for precision agriculture: A review. Preci. Agri. 13: 693–712.

Volume: 06 Issue No: 09

NITROGEN NUTRITION OF NUT CROPS

Article ID: AG-V06-I09-79

Anchal Sharma and Shashi K. Sharma

Department of Fruit Science, College of Horticulture and Forestry

(Dr. Y. S. Parmar University of Horticulture and Forestry)

Neri, Hamirpur (HP) -177001, India

*Corresponding Author : Anchal Sharma

Abstract

Nitrogen plays a central role in keeping nut orchards healthy, driving everything from canopy growth to kernel quality and overall yield. But unlike annual crops, nut trees manage nitrogen through a unique balance: they store reserves in their trunk and branches to power early spring growth, while losing a significant amount of nitrogen permanently when the crop is harvested. Getting nitrogen management right means tuning fertilizer applications to match the tree's actual seasonal demand and crop load, all while avoiding wasteful leaching into groundwater. This review breaks down how nut trees absorb and move nitrogen throughout the year, outlines specific nutrient removal rates across major nut crops, highlights key signs of imbalance, and provides practical 4R stewardship recommendations tailored for both global orchards and local Indian farming conditions.

Keywords: Nut nutrition, Nitrogen remobilization, 4R stewardship, Fertigation, Crop load, Nitrogen use efficiency, Indian horticulture.

Introduction

As perennial woody trees, nut crops differ fundamentally from annual crops and other fruit trees in their nitrogen (N) dynamics. They store considerable amounts of nitrogen both in perennial woody tissues and within their seeds. The N stored in woody tissues is remobilized each

Nut kernels are the major N sinks because proteins constitute a substantial portion of their dry matter. In almond, average N removal stands out to be about 7kg per 100kg of harvested nuts.

season to support early spring vegetative growth before root uptake becomes fully active. Conversely, seed-stored nitrogen is permanently removed from the orchard ecosystem through harvest. This dual-storage mechanism creates a highly dynamic, seasonally variable N demand, contrasting sharply with the linear, single-season demand typical of other fruit crops.

Nitrogen is a foundational macronutrient regulating the growth, yield, and kernel quality of nut crops. It serves as an essential constituent of proteins, chlorophyll, enzymes, and nucleic acids. Adequate N levels are crucial for optimizing vegetative growth, photosynthesis, canopy development, nut development, kernel filling, and protein accumulation. Because proteins constitute a substantial portion of kernel dry matter, nut kernels act as major metabolic N sinks. While the conventional protein conversion factor of 6.25 equates to approximately 16% N in protein, actual values vary among specific proteins and species. For instance, amandin—the primary storage protein in almonds—contains approximately 19.3% N. Consequently, a significant volume of N is exported from orchards during harvest; in almonds, average N removal is estimated at roughly 30.8 kg per 453.6 kg (1,000 lbs) of kernel yield.

While sufficient N supports flower-bud development, tree vigor, and abiotic stress resilience, excessive application triggers undesirable vegetative growth, delays crop maturity, and elevates susceptibility to pests, diseases, and cold injury. Furthermore, surplus nitrate can leach beyond the root zone, threatening groundwater quality and raising critical environmental concerns. Sustainable nitrogen management requires precisely matching fertilizer application rates and timings with seasonal tree demand. Advancing our understanding of the specific roles and dynamics of N in nut production systems is essential for optimizing future orchard management, securing high yields, and minimizing environmental footprints.

Seasonal Nitrogen Dynamics in Nut Trees

A key characteristic of nitrogen nutrition in nut trees is the difference in timing between the tree's nitrogen requirement and its absorption from the soil. During the initial stages of spring growth, perennial nut trees depend largely on nitrogen reserves accumulated in permanent tissues such as roots, trunks, and branches. These stored nutrients support bud break, flowering, and early leaf development before the root system becomes fully active. Studies on almond have demonstrated that significant uptake of soil nitrogen begins only after the canopy is well developed and transpiration increases, usually when leaves have reached approximately half of their final size. Comparable responses have also been reported in walnut and pistachio, where

early shoot growth and flowering are sustained primarily by remobilized nitrogen stored from previous seasons rather than by newly absorbed nitrogen.

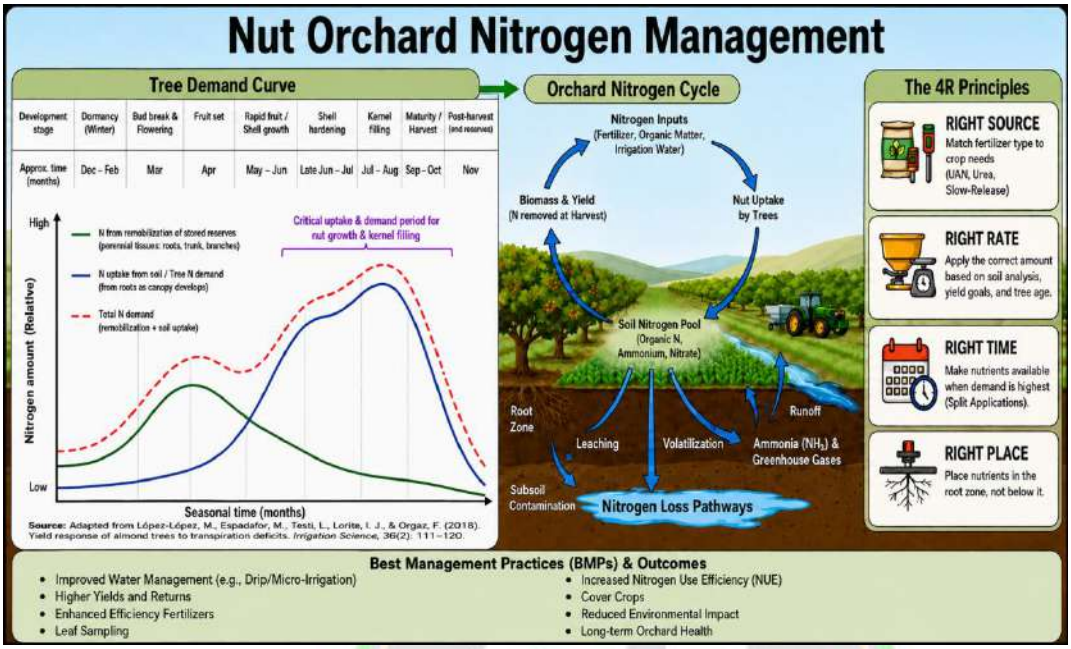
As the growing season progresses and the canopy reaches full expansion, the primary source of nitrogen shifts from internal reserves to soil uptake. This stage coincides with rapid nut growth and kernel development, when nutrient demand is at its highest. In almond, the majority of annual nitrogen absorption occurs between complete leaf expansion and the end of kernel filling, generally from mid-spring to early summer. Nitrogen uptake in pistachio is influenced by its alternate-bearing habit. During heavy crop years, nutrient absorption is concentrated later in the season to satisfy the increased demand associated with nut filling. In contrast, during light crop years, nitrogen uptake is greater during the early vegetative growth period because reproductive demand is relatively low. Following nut maturity and the onset of leaf senescence, root uptake declines considerably, making late-season or dormant-season nitrogen applications less efficient and increasing the likelihood of nitrate losses through leaching.

Trees producing lighter crops generally retain larger reserves of nitrogen, phosphorus, and potassium because fewer nutrients are removed in harvested nuts. These accumulated nutrient reserves are then remobilized during the subsequent heavy-bearing season to support increased reproductive growth. Consequently, nitrogen fertilization programs should consider the crop load and bearing cycle of the orchard rather than relying on a uniform fertilizer application each year.

Symptoms of Nitrogen Deficiency and Excess

Nitrogen deficiency in nut trees is typically expressed as pale green to yellow foliage, with symptoms developing first on older leaves as nitrogen is redistributed to actively growing tissues. As deficiency intensifies, trees may show reduced vigor, smaller nuts, and lower yield. Severe or prolonged deficiency can eventually affect younger foliage as internal nitrogen reserves become exhausted. In contrast, excessive nitrogen supply produces unusually dark green foliage and excessive shoot growth, which can delay tissue maturation and increase susceptibility to frost and winter injury. Excess nitrogen may also favour vegetative growth over reproductive development, potentially reducing fruit set and nut quality. Moreover, surplus nitrogen increases soil nitrate availability and consequently the risk of nitrate leaching, especially following heavy rainfall or irrigation. This risk is particularly high when root activity is low, such as during dormancy or before adequate canopy development in spring. Thus, balanced nitrogen

management is essential to maintain tree vigor, reproductive performance, nut quality, and environmental sustainability.



Crop-Specific Nitrogen Requirements

Nitrogen removal through harvested nuts is an important basis for developing fertilizer budgets because a considerable amount of orchard N leaves the system with the harvested crop. The amount removed varies among nut crops and depends on crop yield, tree nutrient status, and the harvested plant material. In almond, approximately 6.5–7% of the harvested kernel weight can be used as a basis for estimating the nitrogen requirement associated with crop production. Thus, a yield of 454 Kg kernels corresponds to approximately 30-32 kg N. Walnut has a comparatively lower N requirement, with reported removal values of about 13-18 kg N per ton of in-shell nuts. In pistachio, N removal is approximately 13 kg per 454 kg of marketable yield, with additional N required annually to maintain vegetative growth. For pecan and macadamia, crop-specific removal estimates are less extensively established, and fertilizer recommendations are therefore more strongly based on field-calibrated responses. Overall, these differences emphasize the importance of developing crop- and yield-specific N budgets rather than applying a uniform nitrogen rate across nut orchards.

Management Strategy and Application Recommendations

Efficient nitrogen management in nut orchards follows the 4R principle: right source, right rate, right time, and right place. Nitrogen rates should be based primarily on expected crop

yield and adjusted for N supplied through irrigation water, soil mineralization, and organic amendments. Rather than applying the entire requirement at once, the seasonal N dose should be divided into several smaller applications, preferably through fertigation, to improve synchronization with tree demand and nitrogen-use efficiency. Leaf analysis at an appropriate and consistent sampling stage is essential for assessing tree N status and refining fertilizer programs. General crop- wise guidelines are summarized below; local soil and leaf test results should take priority.

Crop	Recommended N rate	Timing / placement
Almond	36.3–45.4 kg N / 453.6 kg kernel target	3–4 splits, full leaf-out to kernel fill (Mar–Jun); fertigation preferred
Walnut	13.6–18.1 kg N / metric tonne expected yield	Even split May–Aug (peak uptake shoot growth to nut fill); avoid dormant-season N
Pistachio	12.7 kg N / 453.6 kg yield + ~11.3 kg N/acre/year tree growth	Pre-season estimate, then split through kernel fill; heavier splits in "on" years
Pecan	45.4–90.7 kg N/acre	60–75% in April (post-bud break), remainder June/August; band under drip line
Macadamia	80–100 kg N/ha per application at flowering (2–3 applications/yr)	Split across flowering and spring flush; evergreen canopy needs year-round monitoring

Source: Compiled and adapted from CDFA Fertilization Guidelines for almond, walnut and pistachio; Oklahoma State University Extension for pecan; and Queensland Government/CSIRO for macadamia

Nitrogen Recommendations for Indian Growing Conditions

India's nut-growing regions fall into two distinct zones with correspondingly different N practices. Almond and walnut are confined to the Temperate Himalayan belt — Jammu & Kashmir, Himachal Pradesh, and Uttarakhand — where due to smaller tree sizes, lower planting densities, and rain-fed or limited irrigation conditions the recommended doses are far lower than in intensively managed Californian orchards. A Kashmir valley trial on 'Waris' almond found that split fertigation at 75% of the recommended dose of fertilizer (RDF) matched or exceeded full-dose soil application in yield and leaf nitrogen status, indicating that Indian temperate-crop N budgets can likely be reduced through fertigation without a yield penalty.

Crop (region)	Recommended N rate	Timing / notes
Almond (J&K)	330 g N + 45 g P per mature tree per year (RDF, Kashmir valley)	Split soil + fertigation; 75% RDF via fertigation in split doses matched or exceeded 100% soil-applied RDF in yield and leaf N
Crop (region)	Recommended N rate	Timing / notes
Walnut (J&K/HP/Uttarakhand)	100 g N per tree in year 1, increasing by ~100 g/tree each year to a mature-tree ceiling	Apply N in early spring at bud break; P and K in small annual doses for the first 5 years, then 45–80 kg P/ha and 65–100 kg K/ha
Cashew (coastal Karnataka, Kerala, Goa, Maharashtra, Odisha, AP)	500 g N + 125 g P_2O_5 + 125 g K_2O per mature tree per year (200 trees/ha); 250 g N/tree under high-density planting (625 trees/ha)	Two split doses — pre-monsoon (May–Jun) and post-monsoon (Sep–Oct); apply in a circular trench along the drip line
Pistachio (Ladakh, trial stage)	Site-specific; leaf-analysis based, following almond/pistachio norms adapted to cold-arid conditions	Limited commercial area; managed under pilot plantings only

Source: Compiled from SKUAST-K (2021), ICAR-DCR, Saa & Brown (2017), and ICAR-CITH technical publications.

ICAR-DCR, Puttur recommends **500 g N, 250 g P_2O_5 and 250 g K_2O per tree per year** for mature, normal-density cashew plantations, applied in two splits during **June–July and September–October**; however, fertilizer doses vary with **high- and ultra-high-density planting systems**.

Conclusion

Nitrogen plays a vital role in the growth, productivity, and nut quality of perennial nut crops. Its management depends on balancing the use of stored nitrogen reserves with seasonal soil nitrogen uptake, which varies among species and is influenced by growth stage and, in pistachio, alternate bearing. Although almond, walnut, pistachio, pecan, and macadamia differ in their nitrogen requirements, all benefit from fertilizer programs based on realistic yield targets, timely nitrogen applications during periods of active uptake, precise placement through fertigation where feasible, and routine leaf nutrient analysis. Adopting these practices enhances nitrogen use efficiency, supports sustainable orchard production, and minimizes the economic and environmental impacts associated with excessive nitrogen fertilization.

Volume: 06 Issue No: 09

THE ROLE OF ESSENTIAL OILS (EO) TO CURTAIL MASTITIS IN DAIRY CATTLE

Article ID: AG-VO6-I09-80

***Dr. D. Divyalakshmi and Dr. N. Kumaravelu**

Department of Livestock Production Management, Madras Veterinary College, Chennai- 600007 Tamil Nadu, India

*Corresponding Author: Dr. D. Divyalakshmi

Introduction

For every dairy farmer, healthy cows are at the heart of a productive farm. Yet one disease continues to quietly surpass animal health, milk quality and farm profitability: bovine mastitis. Mastitis is an infection of the mammary gland, usually caused by bacteria that enter the udder through the teat canal. Some of these bacteria spread from infected cows to healthy animals, while others come from the farm environment, including bedding, housing areas and contaminated surroundings.

The disease can appear in an obvious form, with a swollen udder, abnormal milk and visible signs of illness. But its more troublesome form can remain hidden. Subclinical mastitis may show few or no visible signs, even though it can reduce milk production and compromise milk quality. This makes early detection especially important.

Mastitis is not only a threat to animal health but also a significant economic burden for dairy farmers. Tamilkumaran et al., (2019) reported a high incidence of mastitis, particularly among animals in their first and second lactations. The economic impact becomes evident through the costs associated with treatment and the loss of productivity during illness. The study estimated an average treatment cost of about Rs.417/- per day, with animals remaining ill for an average of 4.19 days, resulting in an overall treatment cost of approximately Rs.1,747.92/- per affected animal. These expenses, coupled with production losses and the additional management required for affected animals, underline the importance of early detection, effective prevention and timely treatment of mastitis at the farm level.

Mastitis is not caused by a single organism. Common contagious pathogens include *Staphylococcus aureus*, *Streptococcus agalactiae* and *Streptococcus dysgalactiae*. Environmental infections can involve organisms such as *Escherichia coli* and *Streptococcus uberis*. Contagious bacteria can move from one animal to another, particularly during milking, while environmental pathogens are often associated with bedding, housing and other farm surroundings. Among the most important organisms is *Staphylococcus aureus*. Infected cows, particularly those with chronic infections, can act as reservoirs, allowing the organism to persist within a herd. Good udder hygiene and careful milking practices therefore remain fundamental tools for protecting healthy animals.

Biofilm formation and resistance development:

One of the reasons mastitis can be so difficult to control is the ability of certain bacteria to form biofilms. A biofilm is essentially a protective community created by microorganisms. It contains bacterial cells embedded in a matrix of polysaccharides, water and other extracellular substances. This structure gives bacteria a degree of protection from both antibiotics and the animal's natural immune defences. Bacteria protected within biofilms can survive challenging conditions and become considerably more difficult to eliminate. This is one reason scientists are increasingly interested in approaches that can act against bacteria in ways different from conventional antibiotics.

The antibiotic challenge

Antibiotics have long been an important weapon against bacterial mastitis. They remain central to the treatment and control of bacterial infections in dairy cattle. But their extensive use has also created a growing concern on antimicrobial resistance. When bacteria develop resistance, medicines that once worked effectively may no longer provide the same level of control. Treatment becomes more complicated, infections may persist, and the options available to farmers and veterinarians can become increasingly limited.

This does not mean antibiotics are obsolete. Rather, it highlights the need for responsible antibiotic use alongside better prevention, rapid diagnosis and the exploration of complementary approaches.

Essential Oils

Essential oils are concentrated natural substances obtained from aromatic plants. They can be extracted from many different parts of a plant—including flowers, leaves, stems, bark,

fruits, seeds, roots and rhizomes.

The Essential oils from thyme, oregano, cinnamon, peppermint or ginger have enormous potential to curb resistant infections. Each plant contains its own distinctive collection of chemical compounds, and these compounds contribute to the plant's characteristic aroma as well as its biological activity. Thousands of essential oils have been identified, although only a smaller proportion are commercially important. They are already used across industries ranging from food and cosmetics to pharmaceuticals and agriculture. Their potential role in animal health is now attracting increasing attention.

Among the plants being investigated for their antimicrobial properties are thyme (*Thymus vulgaris*) and oregano (*Origanum vulgare*). Their essential oils contain compounds that can act against microorganisms associated with mastitis.

Bacterial cells are surrounded by protective membranes that regulate what enters and leaves the cell. Essential oils and some of their components are highly lipophilic, meaning they interact readily with the fatty components of biological membranes. This allows certain compounds to penetrate and disturb bacterial membranes. Once the membrane becomes damaged, the cell can begin losing ions and other essential components. Processes involved in energy production, transport and cellular regulation are disrupted. The bacterial cell may eventually become unable to survive. In other words, rather than simply targeting one biological process, some essential-oil compounds can attack the physical integrity of the bacterial cell itself. Depending on the organism and the circumstances, essential oils may inhibit bacterial growth or contribute to bacterial death.

The chemistry behind the aroma

The smell of an essential oil may be familiar, but its chemistry is remarkably complex. An individual essential oil can contain dozens of different compounds, including terpenes, terpenoids, phenolic compounds, aldehydes, alcohols, acids, esters and other substances. Usually, a small number of major compounds make up a significant proportion of the oil and contribute strongly to its biological properties. Thyme oil, for example, is associated with compounds such as thymol and carvacrol, while peppermint is well known for menthol. Among the compounds of particular interest are phenolics such as thymol, carvacrol and eugenol. These molecules can interact with bacterial membranes and alter their structure, making the membrane more fluid and less stable.

That seemingly simple disruption can have far-reaching consequences for the bacterial cell.

Why one essential oil is not always like another

There is an important catch to the natural appeal of essential oils: natural does not automatically mean uniform. The composition of an essential oil can change depending on the plant variety, climate, soil, age of the plant, plant part used, stage of growth and method of extraction. Even the same plant species can therefore produce oils with different chemical profiles. For consistent results, controlled production and chemical characterization are important. Techniques such as gas chromatography and mass spectrometry can be used to determine the composition of an oil and help identify its major components. This is particularly important if essential oils are to move from promising laboratory findings toward reliable applications in animal health.

Snag in curtailing mastitis:

Clinical mastitis is relatively easy to recognize because changes in the udder and milk can be visible. Subclinical mastitis is much more challenging because the cow may appear perfectly normal. On-farm screening methods such as somatic cell count and the California Mastitis Test can help identify hidden infections. But detecting mastitis is only the first step. Knowing which organism is responsible can be equally important. Identifying the causative bacteria helps veterinarians understand how the infection may be spreading and, where antibiotic treatment is required, choose an appropriate therapy.

Prevention begins with the basics

The search for new antimicrobial tools should never overshadow the fundamentals of mastitis control. Clean housing, good bedding management, proper milking hygiene, healthy teat skin and careful handling of infected animals remain essential. Environmental bacteria thrive when hygiene and housing conditions deteriorate, while contagious organisms can persist when infected animals are not identified and managed appropriately. In many cases, prevention is far less costly than treating an established infection.

Mastitis also carries a financial burden for dairy farmers through treatment expenses, reduced milk production and time lost to illness. The economic impact makes prevention and early detection not merely veterinary priorities, but essential components of profitable dairy farming.

A Plant-Based Future?

Essential oils are not a magic replacement for antibiotics, and much work remains before their full potential in mastitis control can be established. Their appeal lies in their multiple biological activities and their ability to interact with bacteria through mechanisms that differ from many conventional antibiotics. Their activity against bacterial membranes and potentially against organisms with reduced antibiotic susceptibility makes them an intriguing area of research. At the same time, their effectiveness can vary considerably depending on the oil, its chemical composition, the bacterial species involved and the nature and severity of the infection. The future is therefore unlikely to be about choosing between antibiotics and essential oils. Instead, it may involve developing smarter, integrated approaches that combine prevention, rapid diagnosis, responsible antibiotic use and carefully evaluated plant-derived compounds.

From the Farm to the Future

Mastitis is an old problem, but the search for better solutions is entering a new phase. The dairy industry needs treatments that are effective, practical, safe and sustainable. Essential oils offer one intriguing possibility because they bring the enormous chemical diversity of plants into the search for new antimicrobial strategies.

To conclude, healthy udders begin with good management, early diagnosis and responsible treatment. The next generation of mastitis control may not come from a single breakthrough. It may emerge from bringing together the best of modern veterinary medicine, better farm management and the remarkable chemistry already found with Essential oils..

Volume: 06 Issue No: 09

UNDERSTANDING THE BIOLOGY OF MUD CRAB (*SCYLLA SERRATA*) FOR SUSTAINABLE SEED PRODUCTION

Article ID: AG-V06-I09-81

Chandan Gowramma Mahadevaswamy[1], Keisham Geenita[2*] and Chandrabhushan Shivkumar Nishad[1]

[1]Uday Aquaconnects Private Ltd. Mulapolam, Srikakulam, Andhra Pradesh

[2]College of Fishery Science, Udgir, Dist-Latur, Maharashtra, India

*Corresponding Author: Keisham Geenita

Abstract

The genus *Scylla*, commonly known as mud crabs, occurs widely in mangroves, brackish waters, coastal areas, ponds, and intertidal swamps. *Scylla serrata* is an economically important species with high market value and strong domestic and international demand, making it an important exportable resource in India. Mud crab farming provides a valuable livelihood opportunity for coastal fish farmers. However, increasing demand and the expansion of mud crab aquaculture have intensified the collection of wild seed, potentially threatening natural populations. At the same time, irregular availability of hatchery-produced seed and low larval survival remain major constraints to sustainable farming. This article provides an overview of mud crab reproduction, covering maturation, mating, spawning migration, broodstock management, hatchery seed production, and important larval rearing practices. Strengthening hatchery and nursery technologies and improving management practices are essential to reduce dependence on wild seed and support the sustainable development of mud crab aquaculture.

Keywords: Mud crab, biology, reproduction, seed production

Introduction

Large-clawed mud crabs are among the most commercially important seafood species in aquaculture, particularly in Southeast Asian countries, owing to their highly valued meat, nutritional and medicinal attributes, and strong demand in domestic and international markets. The rising importance of live mud crabs as an export commodity has created considerable

opportunities for crab farming, especially given the growing demand for mud crabs. According to MCI (2023), crab exports, excluding imitation products, reached approximately 6,938 tonnes, highlighting the considerable commercial significance of the sector. Mud crabs are particularly suitable for live trade because of their robust nature and ability to withstand prolonged periods of air exposure, particularly under relatively low-temperature conditions. Their high market value is primarily attributed to the desirable taste and nutritional quality of their meat, which contains a range of essential nutrients. The highly valued *Scylla serrata*, commonly known as the mangrove or green crab, is widely distributed throughout the Indo-West-Pacific region. These crabs typically inhabit estuarine and coastal areas associated with mangrove ecosystem, making them highly suitable for coastal aquaculture (Begum et al., 2009). Scylla species are large brachyuran crabs belonging to the family Portunidae, order Decapoda and class Crustacea. They have been recognised as a key species for diversifying coastal aquaculture in several Asian countries, and crab farming is now quite prevalent in India.

The production and culture of mud crabs (*Scylla serrata*) in India is a rapidly evolving sector of coastal aquaculture, shifting from traditional extensive methods toward technologically advanced, intensive approaches. In India, most farmers still rely on wild-caught seed stocks for pond stocking due to irregular availability from the hatcheries. As a result, maintaining consistent production levels throughout the year poses significant challenges for the cultivation industry. The inconsistent success rates of larval crabs remain a significant hurdle in advancing mud crab aquaculture. Furthermore, continued reliance on wild seed may exert additional pressure on natural mud crab populations and may compromise the long-term sustainability of the sector.

On the other hand, the technology for mud crab hatcheries has been implemented successfully, though the survival rate of larvae transitioning to juvenile or instars remains low. High mortality during larval development is primarily due to cannibalism as well as with other biological and environmental factors. In India, hatchery production at near-commercial level was carried out by the Rajiv Gandhi Centre for Aquaculture (RGCA, Tamil Nadu, India) (Shaji et al., 2006). However, seed production is still limited and is insufficient to meet the increasing demand from the farming sector. Furthermore, many of the challenges in mud crab farming are rooted not only in increasing the larval survival rate but also in producing juveniles of stockable size. Addressing these constraints requires improvements in broodstock management, larval

rearing protocols, live-feed management, water-quality control, stocking strategies, cannibalism mitigation, and nursery rearing technologies. In particular, the development of reliable and economically viable hatchery and nursery systems capable of producing uniform, healthy and high-quality seed throughout the year is essential for reducing dependence on wild seed resources. This article provides a comprehensive idea of existing knowledge on mud crab seed production and highlights key priorities for future research aimed at improving technology-driven seed production and promoting sustainable practices in mud crab aquaculture and fisheries.

Reproduction

Biology of Crab Reproduction

The sex of mud crabs can be readily determined based on distinct external morphological characteristics. Males are characterized by a narrow, inverted T-shaped abdominal flap, whereas females possess a broad, semicircular flap. In males, the first and second abdominal segments bear a pair of modified pleopods that function as copulatory organs. In the case of females first four abdominal segments carry pleopods, which are biramous and possess setae for attachments of eggs for brooding. The gonads of mud crabs located beneath the carapace as paired H-shaped organs. In both sexes, the gonadal maturation can be identified by different size and coloration of the gonads. Quinitio et al, (2007) classified the ovarian development of *S. serrata* into five stages: immature (ovary thread like, sometimes difficult to discernible and transparent/transluscent), early maturing (ovary is yellow), later maturing (ovary is massive with apparent lobules and slight orange), fully mature (ovary occupies most of the internal cavity, orange to dark orange) and spent (ovary is similar to early maturing).

Mating

The successful male picks up the female and carries the female around for several days until the female molts. Following ecdysis, copulation takes place while the female remains in the soft-shell condition. During mating, male deposits spermatophore inside the female storage sac (spermatheca) by using the male's first pleopods. The spermatophore can remain viable, for an extended period, potentially for several weeks or months, until fertilization takes place. When the eggs complete vitellogenesis following maturation, they are extruded and fertilized by stored sperms. The eggs adhere to the pleopod hairs and the female is said to be berried or ovigerous.

Migration

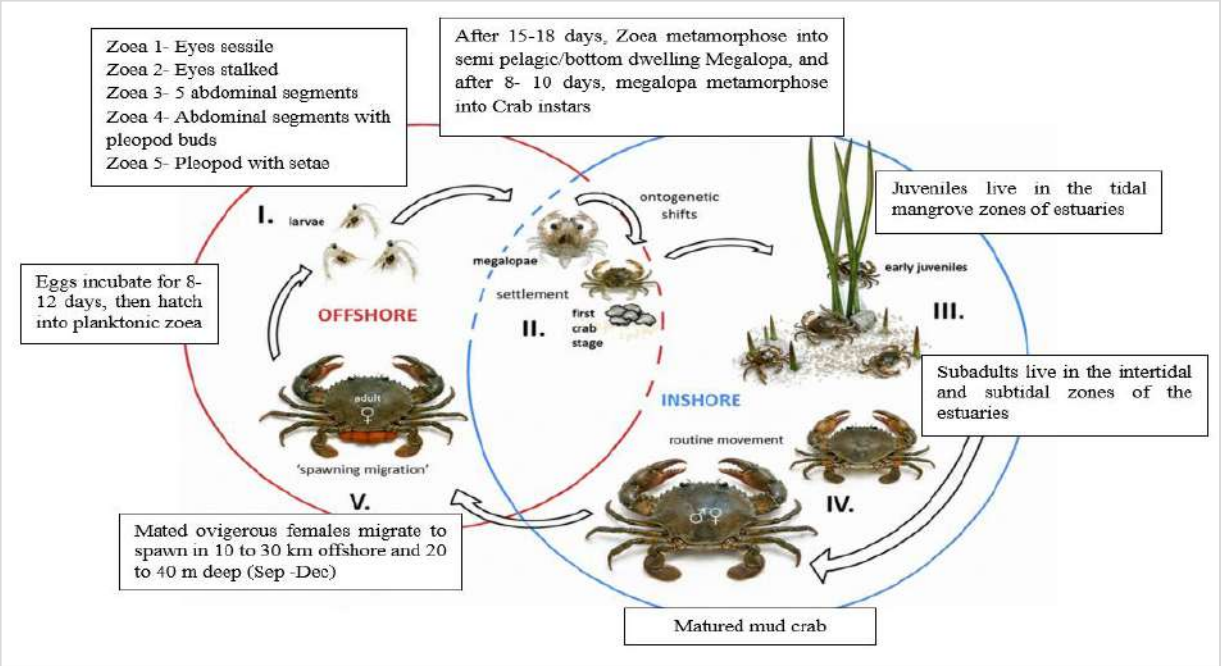


Fig: The life cycle of mud crab (Adapted from Welch and Johnson, 2013 and Alberts-Hubatsch 2016).

A common behaviour in *Scylla* spp. is the offshore migration of females to spawn. The distances these females travel can vary by species and are influenced by environmental factors. Consequently, migration may serve more as a dispersal strategy rather than a necessity for ensuring optimal larval survival conditions (Hill, 1994). The spawning migration of female mud crabs from the mangrove forests to offshore habitats has been well documented and seems to be a behaviour shared by all *Scylla* spp. The spawning migrations of female *S. serrata* into deep water (10–60 m) and often kilometres offshore are argued to provide an effective dispersal mechanism, allowing potential recruitment to areas distant from that occupied by the breeding stock. Following the spawning migration, about a month later, young crabs migrates towards brackish water. According to Heasman, et al. (1985), certain areas may have conditions favourable for larval development within inshore coastal waters, with vast numbers being found in river mouths and along the shoreline.

Hatchery technique and Seed production

Female mud crabs are assessed for ovarian maturity by inspecting the clear membrane located between the first abdominal segment and the carapace. Mature ovaries appear dark orange, while crabs with immature ovaries are light yellow. These mated female brooders are

carefully transported to the hatchery, properly quarantined through disinfection, and maintained in individual tanks. After quarantine, they are placed in a dark environment for conditioning. Eyestalk ablation on one side is used to trigger ovarian maturation and spawning. Providing a sandy substrate is vital. Without sand, females often fail to attach their eggs to their pleopods, resulting in aborted spawns. When females release their eggs, they attach to the pleopod hairs on the abdominal flap. Berried crabs may lose some or all of their eggs due to various factors, including fungal infections, unsuccessful fertilization, nutritional deficiencies, or environmental conditions.

The larval rearing of mud crab starts with stocking Zoea I larvae in dark-coloured rearing tanks at a density of approximately 50–80 larvae per litre. During the early larval stages, particularly Zoea I and Zoea II, rotifers (*Brachionus* spp.) are commonly provided as the primary live feed at densities ranging from 10–60 individuals per ml. From the Zoea III stage onward through the megalopa stage, *Artemia* nauplii are introduced as an important live-feed component, generally maintained at densities of approximately 5–15 individuals per ml. Optimal environmental conditions are essential for successful larval development, with water temperatures maintained at 28–30 °C and relatively high salinity levels considered important for larval survival and developmental performance.

Following metamorphosis, megalopae are transferred to nursery systems, where they may be reared in hapa nets installed within earthen ponds or open-water lagoon environments. Pond-based nursery systems generally provide more favourable conditions for growth because of their greater natural productivity and availability of supplementary natural food organisms. Consequently, megalopa reared in pond-based nursery systems have been reported to attain body weights of up to approximately 10.8 g, demonstrating the potential advantage of earthen pond environments over open-water nursery systems for the production of juvenile mud crabs.

Conclusion

Mud crab (*Scylla serrata*) aquaculture holds significant potential for sustainable coastal development and livelihood improvement because of its high market demand and economic value. However, the limited availability of reliable hatchery-produced seed remains a major constraint. Although hatchery technology has advanced, low larval survival caused by cannibalism, inadequate live-feed management and environmental fluctuations continues to limit production.

Effective broodstock management, proper larval nutrition, strict water-quality control, disease prevention and appropriate stocking densities are essential for improving larval survival. Productive pond-based nursery systems further enhance the growth and survival of megalopae and juveniles. The development of standardised, economically viable hatchery and nursery protocols is therefore critical for producing healthy, uniform seed throughout the year. Reliable hatchery seed production will reduce pressure on wild populations and support the long-term sustainability of mud crab aquaculture. Continued research, technological innovation and improved farm management practices are needed to overcome existing constraints and expand the industry sustainably.

References

Alberts-Hubatsch, H., Lee, S. Y., Meynecke, J. O., Diele, K., Nordhaus, I., & Wolff, M. (2016). Life-history, movement, and habitat use of *Scylla serrata* (Decapoda, Portunidae): Current knowledge and future challenges. *Hydrobiologia*, 763(1): 5–21.

Heasman, M. P., Fielder, D. R., & Shepherd, R. K. (1985). Mating and spawning in the mudcrab, *Scylla serrata* (Forskål) (Decapoda: Portunidae), in Moreton Bay, Queensland. *Australian Journal of Marine and Freshwater Research*, 36: 773–783.

Hill, B. J. (1994). Offshore spawning by the portunid crab *Scylla serrata* (Crustacea: Decapoda). *Marine Biology*, 120: 379–384.

Ministry of Commerce and Industry. (2023). *Press release*. Press Information Bureau, Government of India.https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1932317. 14 June 2023.

Quinitio, E. T., De Pedro, J., & Parado-Estepa, F. D. (2007). Ovarian maturation stages of the mud crab *Scylla serrata*. *Aquaculture Research*, 38: 1434–1441.

Shaji, M., Quinitio, E. T., Samraj, T., Kandan, S., Ganesh, K., Kumar, D., Arulraj, S., Pandiarajan, S., Ismail, S., & Dhandapani, K. (2006). Seed production of mud crab *Scylla serrata* at the Rajiv Gandhi Centre for Aquaculture, Tamil Nadu, India. *Aquaculture Asia*, 11(1): 17–21.

Welch, D. J., & Johnson, J. E. (2013). *Assessing the vulnerability of Torres Strait fisheries and supporting habitats to climate change*. Report to the Australian Fisheries Management Authority. C2O Fisheries.

Volume: 06 Issue No: 09

UNDERUTILIZED VEGETABLES: RICH SOURCE OF NUTRITIONAL AND MEDICINAL VALUE

Article ID: AG-V06-I09-82

Shweta Soni* and Udham Singh

Department of Vegetable Science, College of Horticulture, Banda University of Agriculture and Technology, Banda, Uttar Pradesh (210001), India

*Corresponding Author: Shweta Soni

Abstract

Underutilized vegetables are locally important but commercially neglected crops that possess rich nutritional and medicinal properties, yet receive minimal attention from research, markets and policy systems. These species, including elephant foot yam, drumstick, basella, amaranth, winged bean, chekurmanis, gherkin and kachri, provide high-quality proteins, essential fatty acids, vitamins, minerals and diverse phytochemicals such as betalains, carotenoids, phenolic, triterpenoids and saponins that help prevent or manage malnutrition, anemia, cardiovascular disease, diabetes, inflammation and certain cancers. Their adaptation to marginal lands, low input requirements and multipurpose use, make them strategic crops for enhancing dietary diversity, strengthening resilience of farming systems and conserving agro-biodiversity, especially in rural and tribal communities. By linking these medicinally rich underutilized vegetables with organized value chains, processing, nutraceutical and pharmaceutical industries, farmers can access premium niche markets, generate higher returns per unit area and create additional employment through small-scale processing and marketing enterprises. Therefore, promotion of underutilized medicinal vegetables offers a dual pathway for achieving nutritional and livelihood security: combating hidden hunger and chronic diseases on one side.

Keywords: Underutilized vegetables; medicinal value; nutritional security; phytochemicals; agro-biodiversity; marginal lands.

Introduction

Underutilized vegetables are those that are grown solely for personal consumption rather than on a large commercial scale and are not regularly traded are considered underutilized. Vegetables that are not regularly traded and are grown mainly for personal consumption as opposed to large-scale commercial production are considered underutilized. These crops may offer unique nutritional profiles, climate-adaptive characteristics, or other beneficial properties that haven't been well studied or discovered. Underutilized crops are plant species with untapped potential that could have a significant impact on a number of sectors, such as food security, health, revenue generation, and environmental services. These veggies have a better nutritional profile than other processed vegetables with possible therapeutic uses.

Underutilized food sources, such as minor grains and pulses, root and tuber crops, fruits, vegetables, and non-timber forest products, have the potential to significantly improve food and nutritional security, guard against market disruptions both domestically and internationally, and improve ecosystem services and functions, all of which would increase sustainability. When compared to global crops like tomato and cabbage, many traditional or indigenous vegetables have a higher nutritional content. Traditional vegetables and underutilized legume crops have the potential to significantly contribute to achieving nutritional security because they are a source of vital vitamins, minerals, protein, and other phytonutrients. Expanding the use of underused and neglected crops and species, either as stand-alone crops or planted together with major staples in cereal-based systems, would offer a variety of ways to incorporate temporal and spatial heterogeneity into uniform cropping systems, improving resilience to biotic and abiotic stressors and ultimately resulting in a more sustainable supply of varied and nutrient-dense food. Underutilized vegetables have the potential to improve the health of millions of people living in tribal communities and are essential biological resources for the rural poor. Vegetables that are underutilized significantly affect the lives of people living in rural areas. By boosting the productivity and profitability of farm household labor use in both rural and urban regions, as well as by generating jobs and income, they can put an end to poverty.

Nutritional and Medicinal Value of Underutilized Vegetables

1. Elephant Foot Yam *(Amorphophallus campanulatus)*

Elephant foot yam is regarded as a low-fat, healthful dish that is high in essential fatty acids (Omega-3 fatty acids), which are known to raise blood levels of beneficial anti-cholesterol. The

corms are high in calcium (50 mg/g), phosphorus (34 mg/g), and vitamin A (260 IU/g) and are typically consumed as a vegetable after boiling or baking. Because the leaves have high levels of vitamin A, native communities in India utilise them as a vegetable. The fresh corms are applied externally as an irritant to treat acute rheumatism. Betulinic acid, β-sitosterol, stigmasterol, triacotane, lupeol, and β-sitosterol palmitat are all included. Due to the presence of two triterpenoids, amblyone and salviasperanol, the corms are said to have cytotoxic, antibacterial, and antifungal properties. The plant's tuberous roots, which have blood-purifying qualities, have long been used to treat rheumatism, asthma, piles, tumours, stomach problems, and spleen enlargement.

2. **Drumstick (*Moringa oleifera*)**

Nutrients and antinutrients are present in every component of the plant. Numerous minerals, including Ca, K, Zn, Mg, Fe, and Cu, are found in *M. oleifera* leaves. Moreover, beta-carotene contains vitamins C, D, and E as well as pyridoxine, nicotinic acid, and folic acid. Immature pods have a protein level of about 20.66% and an estimated fibre content of 46.78%. There are 30% of amino acids in the pods, 44% in the leaves, and 31% in the flowers. According to epidemiological research, Moringa oleifera leaves contain anti-inflammatory, anti-ulcer, anti-atherosclerotic, and anticonvulsant properties in addition to being a rich source of nutrients. Skin infections, anaemia, anxiety, asthma, blackheads, blood impurities, bronchitis, catarrh, chest congestion, cholera, and numerous other disorders have all been treated with moringa. Moringa powder can be used to treat anaemia by replacing iron pills.

3. **Basella (*Basella Alba, Basella rubra*)**

Basella contains high levels of vitamins A, C, B9 (folic acid), calcium, magnesium, iron, and antioxidants. Essential amino acids like arginine, isoleucine, leucine, lysine, threonine, and tryptophan are found in the plant, along with a number of vitamins, minerals, and a small amount of soluble oxalates. The plant has 0.4 grams of carbohydrates, 31 kcal of energy, 1.9 grams of fat, 0.3 grams of fiber, 93% moisture, and 3.3 grams of protein. For every 100 grams of edible portion, the micronutrient composition and oxalic acid content were ascorbic acid (15 mg), calcium (187 mg), iron (5.45 mg), and oxalic acid (60 to 84 mg). *Basella alba* has numerous biological actions, including androgenic, anti-diabetic, anti-inflammatory, anti-microbial, antioxidant, anticancer, antiviral, CNS depressant, haepatoprotective, and wound healing effects due to the presence of B-sitosterol and lupeol in the plant.

4. Gherkin (*Cucumis sativus* var. *anguria*)

Gherkins are a type of cucumber that has nearly all the nutrients found in cucumbers. Consuming an average quantity of calories and fats can help maintain weight and lower the risk of significant health issues such as heart disease and cancer. Numerous beneficial substances found in its leaves, including flavonoids, tannins, alkaloids, saponins, and steroids, are utilised for their potent antioxidant properties. Cucumis anguria contains anthraquinones and saponins that have antifungal and antibacterial properties against clinical infections. The seeds are known to have anthelmintic and vermifuge properties, which allow them to eliminate or destroy intestinal worms. A large sweet gherkin contains 114 microgrammes of beta-carotene. The amount of vitamin K in a tiny sweet gherkin is 7.1 microgrammes, or 8% of the 90 microgrammes.

5. Amaranth (*Amaranth tricolor*)

Amaranthus, or red amaranth, is a special source of betalains, β-xanthins, and β-cyanins that may be able to detoxify free radicals. Amaranth's high-quality carbohydrates, dietary fibre, lipids like omega-3 and omega-6, vital amino acids, and other significant components including squalene, tocopherols, phenolic compounds, flavonoids, phytates, vitamins, and minerals are making it a superfood. Amaranthus is used to cure diarrhoea spelling, dysentery, inflammation, gonorrhoea spelling, and piles due to its astringent, appetising, and diuretic qualities. Additionally, amaranthus has long been utilised as a diuretic, antipyretic, antidiabetic, antigonorrhea, antileprotic, and anti-snake venom.

6.* Kachri (*Cucumis callosus)

Cucumis callosus is widely distributed throughout India and is commonly referred to as "Kothimbda" in Gujarat. Constipation, nausea, vomiting, and stomach pain are among the many therapeutic uses for Kothimbda greasepaint with additional spices. Dehydrated Kothimbda has cooling, diuretic, stomach stimulant, coughicide, and vermicide properties. Ascorbic acid, or vitamin C, is the most crucial nutrient when it comes to processing.

7. Chekurmanis (*Sauropus androgynous*)

Chekurmanis leaves are a great source of calcium, iron, zinc, protein, thiamine, riboflavin, vitamin E, vitamin C, and β-carotene. Therefore, chekurmanis is a rare green leafy vegetable that is high in protein, vitamins, and minerals and has the highest quantity of nutrients. Strong antioxidant qualities have been observed for Chekurmanis leaves, most likely because to their high vitamin C and E content.

8. Winged bean (*Psophocarpus tetragonolobus*)

Winged beans are rich in essential nutrients, including 16.10 grammes of fat, 11.04 grammes of protein, and 35.23 grammes of crude fibre and 27.09 grammes of carbs for every 100 grammes. They also provide substantial amounts of essential minerals, such as potassium (584.74 mg), phosphorus (521.09 mg), calcium (340.49 mg), and iron (5.66 mg) per 100 grammes. Vitamins C (14.5 to 128 mg/100 g), thiamine, riboflavin, niacin, vitamin B6, folate, and vitamin A (5240 to 20,800 IU) are all abundant in winged bean leaves. Winged beans have high levels of niacin, which reduces platelet aggregation and helps prevent blood clots. Controlling lipoprotein and Apo lipoprotein levels reduces the risk of cardiovascular diseases associated with the syndrome.



Elephant foot Yam



Drumstick



Basella



Gherkin



Amaranth



Kachri



Chekurmanis



Winged Bean

Conclusion

Underutilized vegetables emerge as nutritionally dense, medicinally rich, and climate-resilient crops that can simultaneously address hidden hunger, lifestyle diseases and livelihood insecurity among rural and tribal communities. Their superior content of vitamins, minerals, fibre and bioactive compounds, combined with adaptation to marginal environments and low-input systems, makes them ideal candidates for diversifying monotonous cereal-based diets and strengthening sustainable food systems. However, to fully harness their potential, focused efforts are needed in germplasm conservation, agronomic standardization, value addition, and market development, with strong linkages to nutraceutical and pharmaceutical industries so that farmers can capture higher value and national nutrition and health goals can be achieved.

Bibliography

Deshmukh, S., & Gaikwad, D. (2013). A review of the taxonomy, ethnobotany, phytochemistry and pharmacology of *Basella alba* (Basellaceae). *Journal of applied pharmaceutical science*.

Gadekar, N.K., Raut, P.S., Bhagyashree, M. and Sanap, G.S., 2023. On *Cucumis callocus*. *WJPR*, *12*(5), pp.2109-2120.

Klimek-Szczykutowicz, M., Gaweł-Bęben, K., Rutka, A., Blicharska, E., Tatarczak-Michalewska, M., Kulik-Siarek, K., Kukuła-Koch, W., Malinowska, M., & Szopa, A. (2024). *Moringa oleifera* (drumstick tree)-nutraceutical, cosmetological and medicinal importance: a review. *Frontiers in Pharmacology*, 15.

Kumar, R., Rajasree, V., Sagar, L., Tripura, U., Karthick, K., Karthick, R. and Prasath, G., 2018. Underutilized vegetables as rich source of medicinal value: a boon for the pharmaceutical industries and farmer income. *International Journal of Chemical Studies*, *6*(4), pp.3320-3323.

Kumaresan, M., Khanchana, K., Anbarasu, M., Ananth, A.V. and Lakshmaiah, K., 2024. Nutritional Content of Underutilized Vegetable Crops: A Potential Source of Human Health and the National Economy. *Current Perspectives in Agriculture and Food Science Vol. 9*, pp.15-28.

Marappan, K., Arumugam, V., Mariyappillai, A., & Subramani, M. (2024). Nutritional Content of Underutilized Vegetable Crops: A Source for Nutritional Security and Human Health. *Asian Research Journal of Agriculture*.

Singh, A., Chaurasiya, A., & Mitra, S. (2016). Assessment of nutritional composition in elephant foot yam (*Amorphophallus paeoniifolius* Dennst- Nicolson) cultivars. *International Journal of Food Studies*, 5

Verma, N.J.K.C., 2020. A review on nutrition value of Amaranth (*Amaranthus caudatus* L.): The crop of future. *Journal of Pharmacognosy and Phytochemistry*, *9*(4), pp.317-319.

Z., Wani, A., Rawat, M., Kaur, H., Das, S., Kaur, T., Akram, N., Faisal, Z., Jan, S., Oyshe, N., Khan, M., & Shah, Y. (2024). Medicinal utilization and nutritional properties of drumstick (*Moringa oleifera*)-A comprehensive review. *Food Science & Nutrition*, 12, 4546 - 4568.

Volume: 06 Issue No: 09

DIGITAL SCREEN TIME AND LANGUAGE DELAY IN CHILDREN: CROSS SECTIONAL STUDY

Article ID: AG-VO6-I09-83

Preetisha Priyam Pathak

UG Student, Department of Human Development & Family Studies, College of Community Science, Assam Agricultural University, Jorhat – 13, India

Introduction

The rapid growth of digital technology has changed the developmental environment of young children. Smartphones, tablets, smart TVs and laptops are now introduced at increasingly early ages. The WHO have raised concerns about excessive screen exposure during the first five years of life, a critical period for speech and language development. In India, affordable smartphones and the growing availability of vernacular-language digital content have further increased screen exposure among infants and toddlers, especially in urban and semi-urban areas. Speech and language development between 1–5 years is essential for cognitive, social and academic development. Children learn language primarily through responsive caregiver–child interactions or "conversational turns," which support vocabulary, pronunciation and sentence development. Un-like human interaction, screen media is largely one-way and cannot respond to a child's communication or provide immediate, personalised feedback. The displacement hypothesis suggests that excessive screen time may replace valuable opportunities for conversation, play and interaction with caregivers.

Recent international studies have strengthened the association between prolonged screen exposure and language delay. Madigan et al. reported that each additional hour of screen time at 24 months was associated with higher odds of expressive language delay at 36 months. Japanese research similarly found smaller expressive vocabularies among infants exposed to more than two hours of screen time daily. Indian studies, including those from Tamil Nadu and Maharashtra, have also reported excessive screen use as an important associated factor among preschool children referred for speech-language concerns.

However, important research gaps remain in India, particularly regarding the dose-response relationship, differences between interactive educational and passive entertainment content, and language outcomes across the entire 1–5-year age range. Recent reviews suggest that more than 60% of children under five in several populations do not follow recommended screen-time guidelines.

Association of Screen Time with Neurological Development.

Digital screen time refers to the amount of time a child spends viewing, interacting with, or engaging with content through a screen-based electronic device. It includes both passive activities, such as watching videos, and active activities, such as playing games, video-calling, or using educational applications.

Children below five years are particularly vulnerable to excessive screen exposure because this is a critical period of rapid brain growth, maturation and neural development. Higher exposure to electronic media has been associated with adverse neurocognitive outcomes, behavioural difficulties and delayed speech and language development.

Neuroimaging studies, including functional and structural MRI research, have reported associations between excessive screen use and altered microstructural integrity of brain regions involved in language, learning and cognitive processing. Excessive use of electronic devices among infants and toddlers has also been associated with poorer receptive language, speech and motor skills.

Prolonged exposure to handheld devices and other digital media has additionally been linked with attention problems, hyperactivity, impulsivity, psychological distress and behavioural difficulties. When screen use becomes excessive—particularly when it exceeds recommended limits—it may interfere with activities essential for healthy neurological development, including sleep, physical activity, exploration, play, social interaction and caregiver–child communication. Consequently, cognition, motor development, learning, memory and emotional well-being may be affected.

The age at which screen exposure begins may also be important.

Comparison Between Children Of Different Ages

Compared with children who were typically introduced to television around four years of age in earlier generations, children born after 2000 have increasingly encountered screens during

infancy. Earlier and more frequent exposure has been associated in some studies with greater risks of attention difficulties, impulsivity and mental-health-related symptoms.

The developmental effect of screen exposure also depends on the child's age, type of content, duration of exposure and the level of adult interaction. Educational media may be more beneficial when it is age-appropriate, limited and accompanied by caregiver interaction. However, excessive or uncontrolled exposure may displace real-world experiences that are essential for speech, language, vision, cognition and overall development.

Research by Patricia Kuhl and colleagues on early language learning demonstrated the importance of human social interaction in language acquisition. Infants learn language substantially more effectively from responsive human interaction than from recordings alone. Therefore, even highly engaging educational videos cannot fully replace the conversational exchange, emotional responsiveness, creativity and imaginative experiences provided by real people.

Screen Time and Covid – 19

The COVID-19 pandemic and prolonged lockdowns significantly increased children's exposure to digital screens. With schools, parks and outdoor activities closed, children spent more time at home using smartphones, watching cartoons, playing video games and accessing other forms of digital entertainment. The shift to online education further increased screen exposure because digital devices became essential for learning. Although the pandemic has subsided, many children continue to find it difficult to return to routines with limited screen use.

A review of 11 studies examining electronic media use found a notable association between **excessive** screen exposure and difficulties in speech and language development, particularly among infants and toddlers. Although digital media can provide education and entertainment, prolonged use may reduce the time children spend in meaningful communication and interactive activities. Therefore, parental supervision and appropriate limits on screen exposure are important.

Several factors contributed to increased screen use during and after the pandemic. Children had fewer opportunities for school attendance, outdoor play, social interaction and physical activities. In addition, busy parents may use screens to keep children occupied when they are bored, restless or eating. In households where both parents work, limited time for direct interaction may further increase a child's dependence on digital devices.

However, screen-based activities cannot fully replace the developmental benefits of playing, talking and interacting with parents, siblings and peers. Face-to-face interactions provide opportunities to learn new vocabulary, understand emotions, practise communication and develop creativity and imagination. Excessive screen use may instead encourage social withdrawal, reduce peer interaction and limit real-world learning experiences.

Another concern is that young children may have difficulty distinguishing fictional content from real-life experiences, particularly when they are exposed extensively to animated or highly imaginative content. Prolonged isolation with screens may consequently affect social and cognitive development.

Overall, research suggests that the developmental impact of screen exposure depends not only on duration but also on content, context and parental involvement. Whether screens are used for education or entertainment, excessive and poorly supervised use may interfere with normal development. Balanced screen use, active parental involvement, adequate sleep, outdoor play and regular face-to-face communication are therefore essential for healthy speech, language, cognitive and social development.

How Excessive Screen Time Affect Language Development?

Excessive screen time may influence children's language development by reducing the quality and quantity of real-life interactions through which language is naturally acquired. According to Vygotsky's Sociocultural Theory, language develops through social interaction with more knowledgeable individuals, particularly parents and caregivers. Excessive engagement with screens can displace parent–child conversations, face-to-face communication, and collaborative activities, thereby reducing opportunities for children to learn through scaffolding and the Zone of Proximal Development (ZPD). Similarly, Bandura's Social Learning Theory emphasizes that children learn behaviours, including language and communication patterns, through observation, imitation, and interaction with others.

Passive screen viewing may provide language models, but it does not always offer the responsive feedback and opportunities for imitation that occur during direct social interaction. From the perspective of Piaget's Cognitive Development Theory, young children develop knowledge through active exploration, manipulation of objects, symbolic play, and interaction with their environment. When excessive screen use replaces imaginative, pretend, and social play, children may experience fewer opportunities to use language for problem-solving,

storytelling, negotiation, and self-expression. The Social Interactionist perspective, associated with researchers such as Jerome Bruner, further highlights the importance of responsive caregiver–child interactions, turn-taking, joint attention, and conversational routines in language development. Excessive screen exposure may reduce these opportunities, particularly when children engage in solitary and passive viewing. In addition, prolonged screen use, especially before bedtime, may interfere with sleep and daily routines, which can indirectly affect attention, learning, memory, and communication. Therefore, excessive screen time should be understood not simply as exposure to digital media, but as a potential displacement of essential developmental experiences, including responsive communication, social interaction, play, exploration, and caregiver engagement, all of which are fundamental to healthy language development

Conclusion

In the contemporary era of digital natives, exposure to smartphones, tablets, televisions, and other digital media has become increasingly common during early childhood. Emerging evidence suggests that excessive screen exposure may be associated with adverse developmental outcomes, particularly in the domain of speech and language development among children aged 1–4 years. The findings indicate that the duration of screen exposure may be a more significant predictor of speech delay than the type or quality of content viewed. Children exposed to screens for more than four hours per day demonstrated a greater likelihood of speech delays, with younger children and boys appearing to be particularly vulnerable. These findings can be interpreted through Bronfenbrenner's Ecological Systems Theory, which proposes that child development is influenced by interactions between the child and multiple environmental systems. Excessive screen use may alter the child's immediate microsystem by reducing opportunities for direct interaction with parents, siblings, peers, and other caregivers, thereby influencing language-learning experiences.

The findings can also be understood through Information Processing Theory, which views children as active processors of information whose attention, encoding, storage, and retrieval abilities develop progressively during early childhood. Prolonged and rapidly changing digital stimulation may compete with developmentally appropriate activities requiring sustained attention and active processing, potentially affecting the acquisition and use of language. Furthermore, Attachment Theory proposed by John Bowlby emphasizes the importance of

consistent, responsive caregiver–child relationships for healthy emotional and cognitive development. Excessive screen use, particularly when it replaces responsive caregiver interaction, may reduce opportunities for joint attention, emotional responsiveness, and reciprocal communication that support early language learning. Interestingly, the observed protective association of multilingualism with speech delay may indicate that children exposed to multiple languages experience greater opportunities for varied linguistic input and communication, although this relationship requires further investigation and should not be interpreted as evidence that multilingualism itself prevents language delay. The study also reports a close association between parental screen use and children's screen exposure, highlighting the importance of parental behaviour and the home environment. This is consistent with the concept of parental modelling, whereby children may acquire behavioural patterns by observing and imitating adults in their immediate environment.

However, these findings should be interpreted cautiously because an association between screen exposure and speech delay does not establish a direct causal relationship. Other variables, including the quality of parent–child interaction, socioeconomic conditions, parental education, home language environment, developmental characteristics, and existing communication difficulties, may also contribute to observed outcomes. Therefore, longitudinal cohort studies are needed to clarify temporal and causal relationships and to determine whether reducing excessive screen exposure can improve or reverse language-related difficulties. Overall, the evidence emphasizes the need for pediatricians, parents, educators, and policymakers to promote developmentally appropriate and balanced digital-media practices, while ensuring that screen use does not replace the face-to-face interaction, responsive caregiving, play, and rich linguistic experiences that are essential during early childhood.

References

The Impact of Screen Time on Speech and Language Development in Children Aged 1 to 5 Years | IJMPR https://ijmpr.in/article/the-impact-of-screen-time-on-speech-and-language-development-in-children-aged-1-to-5-years-2717/

Relationship Between Screen Usage and Speech Delay in Children Aged One to Four Years in Dubai and the Northern Emirates - PMC https://share.google/rpclEcxjy9YsqdDOL

https://share.google/0ywMVVC3VJ13l4UrA

Handheld screen time linked with speech delays in young children | AAP News | American Academy of Pediatrics https://share.google/7hCFHROoNivtYIUei

https://asuj.bestbookbuddies.com/cgi-bin/koha/opac-detail.pl?biblionumber=13107&query_desc=ti%2Cwrdl%3A%20Child%20development

Volume: 06 Issue No: 09

EARTHWORM COLLECTION AND MULTIPLICATION TECHNIOUES FOR SUSTAINABLE VERMICOMPOSTING

Article ID: AG-VO6-I09-84

K. Nalini

Associate Professor (Agronomy), Veterinary College and Research Institute, Namakkal

Tamil Nadu, India

Introduction

Earthworms that feed on leaf litter in the soil can be collected and reared using simple methods to generate the surplus population needed for vermicompost production. This enables the production of vermicompost within a very short period. Collecting these earthworms from the soil is a crucial step in the vermicompost production process; specifically, the worms that feed on surface leaf litter are the ones suitable for this purpose.

These earthworms are red or reddish-brown in color. They readily consume all types of crop residues and convert them into vermicompost. Earthworms that inhabit deeper soil layers do not consume significant amounts of crop residue; furthermore, digging them up can cause injuries that may lead to their death. Therefore, collecting and using earthworms that inhabit the topsoil is the best method. There are several methods such as electrical, chemical, and organic techniques to collect these earthworms.

Electrical Method

In many countries, earthworms are collected using an electrical method. Specifically, varying electrical charges are used to create vibrations in the soil, forcing the earthworms to emerge so they can be gathered. A significant number of earthworms often die during this process; these dead worms are then used as fish feed. This hazardous method is not practiced in our country.

Chemical Method

Chemical substances such as potassium permanganate and formalin are used to collect earthworms in this method. When a two-percent solution of these substances is poured onto the soil in shady, moist areas, the earthworms emerge from the ground. Earthworms collected in this

manner must be washed thoroughly in clean water several times before being used for vermicompost production.

It takes a long time for the earthworms to recover to their normal state from the effects of these chemicals, and significant numbers of them often die in the process. Furthermore, since this method draws earthworms from the deeper soil layers to the surface, they cannot be utilized for vermicompost production.

Additionally, procuring these chemicals and preparing solutions with the precise concentrations required is extremely difficult.

Hand collection method

- Select a **moist, shaded location** containing plenty of decomposed organic matter.
- Remove the upper layer of dry leaves or soil gently.
- Collect visible earthworms manually using a hand trowel.
- Carefully lift the soil containing earthworms and place them in a container containing **moist soil or partially decomposed organic matter**.
- Avoid direct exposure to sunlight and excessive heat.
- Transport the collected worms to the multiplication unit as soon as possible.

Mustard-water method

This method is useful when earthworms are present deeper in the soil.

- Prepare a dilute mustard-water solution.
- Sprinkle or gently pour the solution over a small area of moist soil.
- Earthworms move toward the surface because of irritation caused by the solution.
- Collect the worms manually as they emerge.
- Wash them gently with clean water before transferring them to the multiplication bed.

The solution should be mild; concentrated mustard solution can injure earthworms.

Baiting method

Earthworms can be easily collected without causing any harm, utilizing readily available natural materials such as cow dung, sugarcane press mud, molasses, curd, buttermilk, and fruit juice.

First, apply patches of cow dung slurry in shady areas of the field or along the edges of the drainage channel in the cattle shed.

Next, spread straw or dried leaves over it, sprinkle water, and cover the area with a damp gunny sack. You must sprinkle water on the sack daily to keep it moist. By doing this, you will observe a large number of earthworms gathering within 10 to 15 days, attracted by the moisture and the cow dung solution; these can then be easily collected.

When the soil from that area is collected, earthworm cocoons are gathered along with it. Each cocoon produces 3 to 5 earthworms. Earthworm populations are higher in fields where bananas and legumes are cultivated.

In shady and moist areas of such lands, apply a mixture containing equal parts of cow dung slurry, jaggery syrup (or sugarcane molasses), and jaggery. Then, cover the mixture with straw or dried leaves and maintain moisture; earthworms will soon begin to breed there.

Earthworms are attracted to the scent of decomposed cow dung solution and sugar solution; as they congregate in one spot, they can be easily collected. Similarly, milk, curd, and buttermilk can be used to gather earthworms. Highly acidic fruit juices may also be used. Since earthworms collected in this manner acclimatize to the local temperature conditions, mortality rates among them remain low.

Research has revealed that earthworms can be collected very easily and quickly by using the leaf extract of the *Polygonum hydropiper* plant. *Polygonum hydropiper* (commonly known as water pepper or marshpepper knotweed) is highly effective for earthworm collection and extraction because it acts as a powerful natural earthworm repellent.

When an aqueous solution of the plant is applied to the soil, it irritates the earthworms' neurosecretory and nervous systems. To escape the irritation, a large number of worms quickly swarm out of their burrows to the soil surface.

Anglers use this method to collect live earthworms for fish bait (angling). It is also utilized by gardeners and landowners to control surface activities, such as excessive casting (unpleasant worm droppings) on lawns or to prevent earthworms from accidentally uprooting delicate seedlings. The aerial parts (leaves and stems) of the plant are crushed and soaked or boiled in water to create an aqueous plant extract. This liquid is sprayed or poured directly over damp soil where earthworms live.

This method is superior to collecting earthworms using chemical methods.

Earthworms collected using this method return to their natural state within a very short time and consume crop residues rapidly and in large quantities during the manure production

process. Furthermore, they possess a high reproductive capacity. Such earthworms should be reared and propagated using appropriate methods.

By multiplying earthworms collected through organic methods, one can obtain the earthworms needed for fertilizer production. There are two methods for this: the pit method and the box or tank method.

Pit-based rearing:

For this method, dig a pit measuring 1x1x1 meter (length, width, and depth) in a shaded area, such as a garden or cattle shed. Fill the pit with 50 kg of well-dried cow dung, ensuring it is thoroughly crumbled. Then, introduce and rear specific earthworm species such as *Perionyx excavatus, Eudrilus eugeniae,* or *Eisenia fetida* into the pit.

Cover this with straw and sprinkle water regularly to maintain the right moisture level. Mature earthworms will mate and lay 3–4 cocoons within a few days. Once the incubation period is over, 3–5 young earthworms will emerge from each cocoon.

Five to nine earthworms emerge from the egg cocoon of species such as *Eudrilus eugeniae* and *Eisenia fetida*. Their population increases three- to five-fold within 40 to 50 days. Each young earthworm becomes ready for reproduction in 30 to 40 days. Under favorable weather conditions specifically during cooler periods their population can increase up to tenfold.

Box or Tank Rearing Method:

Earthworms can be reared in wooden boxes or cement tanks. For this purpose, a wooden box or cement tank measuring 50 x 25 x 15 cm (length, width, and height) may be used. Fill the bottom quarter of the container with soil collected from the same area where the earthworms were sourced, and place well-pulverized crop waste over it.

Next, fill a container with 10 kg of shade-dried, powdered cow dung. Sprinkle water over it and allow it to decompose for two days. Finally, stir the mixture to release any internal heat, and then introduce 100 fully grown '*Eudrilus eugeniae'* earthworms. It is advisable to erect a shelter to protect the setup from rain and direct sunlight. Sprinkle water daily to maintain a moisture level of 50–60 percent.

When the earthworms exhaust their food supply, fresh cow dung should be added. Occasionally, materials such as wheat bran, pulse bran, vegetable waste, and nitrogen-rich leaves from plants like Gliricidia, Subabul, and Portia can also be added along with the cow dung.

When reared in this manner, the earthworm population has the potential to increase twenty-fold within one to two months.

Points to Consider in Earthworm Rearing

- Types of waste and the quantities to be applied, crop residues are not waste they generate income. When introducing earthworms into the tank, avoid adding dead or severed ones. The tank and the surrounding area must not be excessively moist, if there is too much moisture, the earthworms will crawl out of the tank.
- The earthworm rearing tank must be covered with iron mesh to prevent the entry of predators such as rats and bandicoots.
- The moisture level of the waste material must be maintained correctly, both a lack of moisture and excessive moisture can be harmful.
- To control predators of earthworms such as ants, millipedes, and cockroaches, sprinkling of neem cake powder. The use of chemical pesticides is not advisable.
- Earthworms should be collected and multiplied using the simple methods mentioned above and then utilized to produce vermicompost.

Volume: 06 Issue No: 09

FEED THE SOIL, GROW THE FUTURE: SMART NUTRIENT MANAGEMENT FOR SUSTAINABLE FARMING

Article ID: AG-V06-I09-85

R. Raja Priya[1] and **S. Pranava Mari Muthu**[2]

[1]Assistant Professor, Department of Agronomy, Roever Agricultural College, Perambalur, Tamil Nadu, India.

[2]M.Sc. (Agriculture) First Year Student, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.

*Corresponding Author: R. Raja Priya

Introduction

Modern agriculture has significantly enhanced crop productivity through improved varieties, irrigation facilities, mechanization and fertilizer use. However, intensive cultivation and excessive or unbalanced fertilizer application can gradually deplete soil fertility, raise production costs and contribute to environmental concerns. Sustainable agricultural development therefore requires not only higher food production but also the long-term conservation of soil health and productivity.

Sustainable nutrient management

Sustainable nutrient management is a systematic approach that provides crops with essential nutrients in the appropriate source, quantity, timing and placement while protecting soil health and reducing nutrient losses. It integrates organic amendments, mineral fertilizers, biofertilizers, crop residues and modern technologies to improve nutrient-use efficiency.

Thus, sustainable nutrient management seeks to balance crop productivity, soil fertility, farm profitability and environmental stewardship.

The 4R Principle:

1. Right Source

The selected nutrient source should be suited to the crop requirement, soil characteristics and prevailing field conditions. Farmers can integrate mineral fertilizers with compost,

farmyard manure, crop residues and biofertilizers as appropriate.

2. Right Rate

Fertilizer rates should be determined from soil fertility status, crop nutrient requirements and realistic yield targets. Higher fertilizer application does not automatically result in higher crop yields.

3. Right Time

Nutrients should be supplied in accordance with the crop's periods of greatest demand. Dividing nitrogen applications into suitable doses instead of applying the full amount at once can minimize losses and improve nutrient-use efficiency.

4. Right Place

Fertilizers should be positioned so that developing roots can access nutrients efficiently. Depending on the crop and fertilizer type, band placement, localized application, fertigation and root-zone placement can help improve nutrient recovery and reduce losses.

Soil Testing: The Foundation of Nutrient Management

Effective nutrient management begins with a clear understanding of soil conditions. Soil testing provides information on the availability of major nutrients and key properties such as pH, organic carbon and electrical conductivity. These results help farmers identify nutrient constraints and formulate an appropriate nutrient-management programme. Periodic soil testing also enables long-term monitoring of changes in soil fertility.

Recycling Crop Residues: Turning Waste into Nutrients

Crop residues should not be viewed merely as farm waste; they can serve as valuable sources of nutrients and organic matter.Materials such as rice straw, maize stalks, groundnut residues, pulse residues and other crop biomass contain nutrients taken up during crop growth. Rather than burning or unnecessarily removing these materials, farmers can return them to the production system through composting, soil incorporation, mulching or other suitable practices.

Recycling residues helps close the nutrient cycle within the farm and reduces the loss of potentially useful resources.For instance, incorporating suitable crop residues can return organic carbon and nutrients to the soil while supporting biological activity and nutrient cycling.

Green Manuring: Growing Fertility Before Growing the Crop

Green manure crops are cultivated mainly to enhance soil fertility and organic matter rather than for direct harvest.Leguminous green manure crops can enrich the soil with

biologically fixed nitrogen, while incorporation of their biomass contributes organic matter and supports soil fertility.In Indian farming systems, crops such as sunnhemp and dhaincha are widely used as green manure crops.

Green manuring is especially valuable in intensive cropping systems where maintaining adequate soil organic matter is difficult.

Biofertilizers: Harnessing the Power of Microorganisms

Soil is a dynamic living ecosystem inhabited by a vast community of microorganisms. Beneficial microorganisms can contribute to improved nutrient availability and acquisition by crops.Biofertilizers containing microorganisms such as Rhizobium, Azotobacter, Azospirillum and phosphate-solubilizing organisms can enhance nutrient acquisition when suitable soil and environmental conditions prevail.

Mycorrhizal fungi can further enhance root nutrient acquisition, particularly phosphorus uptake, under favorable soil conditions.Biofertilizers should not be viewed as a universal replacement for fertilizers. Their effectiveness depends on soil conditions, crop, microbial strain, application method and environmental factors. They are most useful as a component of an integrated nutrient management programme.

Precision Nutrient Management

Digital technologies are increasingly being incorporated into modern nutrient-management practices. GPS-based soil mapping, soil sensors, remote sensing, drones, satellite imagery and digital decision-support systems can help identify nutrient and crop variability within fields.

Nutrient status can vary considerably across a single field, with some areas having adequate supplies and others showing deficiencies. Consequently, applying an identical fertilizer rate across the entire field may result in inefficient nutrient use. Precision nutrient management enables nutrient applications to be adjusted according to spatial variation and changing crop requirements over time.

Foliar Nutrition: A Targeted Approach

In some situations, nutrients can be supplied directly through the foliage. Foliar application can be useful for correcting selected micronutrient deficiencies or supplementing nutrient supply during critical crop-growth stages.This approach can be particularly useful when soil conditions limit the availability of specific nutrients.

Foliar nutrition should complement, rather than substitute for, sound soil-based nutrient management. Appropriate concentration and application timing are essential because overly concentrated sprays can cause leaf injury.

Micronutrients: Small Quantity, Big Impact

Although farmers commonly emphasize nitrogen, phosphorus and potassium, micronutrients such as zinc, iron, boron, manganese, copper and molybdenum are equally essential for healthy crop growth.Despite being required in relatively small amounts, deficiencies of these elements can markedly reduce crop growth, yield and produce quality.

Soil testing, plant tissue analysis and field-based visual diagnosis can assist in identifying nutrient deficiencies. Timely correction of micronutrient deficiencies can substantially improve crop performance in situations where the deficiency is limiting growth.

Nutrient Management and Soil Health

Sustainable nutrient management extends beyond supplying nutrients to crops; it also involves maintaining soil as a healthy and productive biological system.Regular incorporation of organic matter can stimulate soil microbial activity, improve soil aggregation and increase water-holding capacity.

Healthy soils generally create favorable conditions for root development, microbial activity and efficient nutrient cycling.Practices including crop rotation, cover cropping, residue recycling, reduced soil disturbance and regular organic-matter addition can therefore strengthen nutrient-management programmes.

The Role of Modern Technology

The future of nutrient management will increasingly rely on the effective integration of agricultural knowledge with digital and precision technologies.Smartphone-enabled soil-testing services, digital fertilizer recommendations, sensor-based monitoring, drones, satellite observations, artificial intelligence and farm-management platforms can support more informed nutrient-management decisions.

Artificial intelligence can potentially integrate soil characteristics, weather information, crop-growth observations and historical yield data to generate more site-specific nutrient recommendations.

A Practical Nutrient Management Model for Farmers

A simple farm-level strategy can follow these steps:

Step 1 – Test the soil
↓
Step 2 – Understand crop nutrient requirements
↓
Step 3 – Identify available organic and inorganic nutrient sources
↓
Step 4 – Prepare a field-specific nutrient plan
↓
Step 5 – Apply the right source at the right rate, time and place
↓
Step 6 – Monitor crop growth and nutrient status
↓
Step 7 – Correct deficiencies when necessary
↓
Step 8 – Recycle crop residues and organic resources
↓
Step 9 – Evaluate yield, nutrient-use efficiency and soil health

Following this sequence can gradually transform fertilizer use into a more efficient, site-specific and sustainable management system.

Economic Benefits for Farmers

Sustainable nutrient management can contribute directly to improved farm profitability.Unnecessary fertilizer applications raise production costs without necessarily increasing yield. Efficient nutrient management enables farmers to direct fertilizer investments toward situations where they are most likely to provide an agronomic and economic benefit.

Improved nutrient-use efficiency can reduce input wastage, while better soil health can contribute to more stable productivity over the long term.Thus, sustainability is not solely an environmental objective; it is also an economic strategy for reducing unnecessary input expenditure and safeguarding the long-term productive capacity of agricultural land.

Healthy soil + efficient nutrients + modern technology = sustainable farming.

References

1. Food and Agriculture Organization of the United Nations. (2017). *The future of food and agriculture: Trends and challenges*. FAO.
2. Food and Agriculture Organization of the United Nations. (2021). *The state of the world's land and water resources for food and agriculture: Systems at breaking point*. FAO.

3. International Fertilizer Association. (2022). *Fertilizer use and sustainable nutrient management*. International Fertilizer Association.
4. Johnston, A. E., & Bruulsema, T. W. (2014). 4R nutrient stewardship for improved nutrient use efficiency. *Journal of Environmental Quality, 43*(3), 815–821.
5. Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science, 304*(5677), 1623–1627. https://doi.org/10.1126/science.1097396
6. Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., & Niggli, U. (2002). Soil fertility and biodiversity in organic farming. *Science, 296*(5573), 1694–1697. https://doi.org/10.1126/science.1071148
7. Prasad, R. (2009). Efficient fertilizer use: The key to food security and better environment. *Journal of Tropical Agriculture, 47*(1–2), 1–8.
8. Robertson, G. P., & Vitousek, P. M. (2009). Nitrogen in agriculture: Balancing the cost of an essential resource. *Annual Review of Environment and Resources, 34*, 97–125. https://doi.org/10.1146/annurev.environ.032108.105046
9. Roy, R. N., Finck, A., Blair, G. J., & Tandon, H. L. S. (2006). *Plant nutrition for food security: A guide for integrated nutrient management*. Food and Agriculture Organization of the United Nations.
10. Stewart, W. M., Dibb, D. W., Johnston, A. E., & Smyth, T. J. (2005). The contribution of commercial fertilizer nutrients to food production. *Agronomy Journal, 97*(1), 1–6. https://doi.org/10.2134/agronj2005.0001
11. Vanlauwe, B., Wendt, J., Giller, K. E., Corbeels, M., Gerard, B., & Nolte, C. (2014). A fourth principle is required to define conservation agriculture in sub-Saharan Africa: The appropriate use of fertilizer to increase crop productivity. *Field Crops Research, 155*, 10–13. https://doi.org/10.1016/j.fcr.2013.10.002
12. Zhang, X., Davidson, E. A., Mauzerall, D. L., Searchinger, T. D., Dumas, P., & Shen, Y. (2015). Managing nitrogen for sustainable development. *Nature, 528*, 51–59. https://doi.org/10.1038/nature15743

Volume: 06 Issue No: 09

MANGROVES UNDER SALINITY STRESS: PHYSIOLOGICAL, BIOCHEMICAL, MOLECULAR AND ECOLOGICAL MECHANISMS OF SALT TOLERANCE

Article ID: AG-VO6-I09-86

***Krishnendu Debnath[1] and Hemlata Kabadwal[2]**

[1]Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Horticulture, VCSG UUHF, Bharsar, Pauri Garhwal-246123, Uttarakhand, India

[2]Department of Forest Product and Utilization, College of Forestry, VCSG UUHF, Ranichauri, Tehri Garhwal-249199, Uttarakhand, India

*Corresponding Author: Krishnendu Debnath

Abstract

Mangroves are highly specialized woody plants occupying intertidal environments where salinity, waterlogging, tidal inundation, nutrient limitation and fluctuating freshwater availability impose strong environmental constraints. Their exceptional capacity to survive in saline habitats results from a combination of morphological, anatomical, physiological, biochemical and molecular adaptations. Salinity primarily induces osmotic stress, ionic toxicity, nutritional imbalance and oxidative stress, which can adversely affect water relations, photosynthesis, growth and reproduction. Mangroves have evolved several mechanisms to overcome these limitations, including salt exclusion at the root level, selective ion transport, vacuolar ion sequestration, salt secretion through specialized leaf glands, succulence, osmotic adjustment and enhanced antioxidant defense. These mechanisms differ among mangrove species, resulting in species-specific responses to salinity and contributing to mangrove zonation along environmental gradients. Salinity also interacts with flooding, nutrients, light, temperature and freshwater availability to regulate mangrove establishment and development. Recent molecular and omics-based studies have expanded understanding of ion transporters, Na^+/H^+ antiporters, stress-responsive genes and antioxidant pathways involved in salt tolerance. This article reviews the major physiological, biochemical, molecular and ecological mechanisms through which mangroves tolerate salinity and discusses their implications for conservation, restoration and

climate-resilient coastal ecosystems.

Keywords: Mangrove, Salinity stress, Salt tolerance, Ion homeostasis, Osmotic adjustment, Salt exclusion, Salt secretion, Antioxidants, Mangrove ecology, Climate change.

1. Introduction

Mangrove forests are distinctive coastal ecosystems dominated by woody plants capable of surviving in periodically inundated and saline environments. They occur primarily along tropical and subtropical coastlines, estuaries, deltas, lagoons and sheltered intertidal areas. Mangrove vegetation provides important ecological functions, including coastal protection, sediment stabilization, nutrient cycling, habitat provision and carbon storage. However, mangrove establishment and growth are controlled by a combination of environmental factors, including salinity, flooding, nutrients, light, temperature and hydrological conditions (Krauss et al., 2008).

Salinity is one of the most important environmental constraints affecting mangrove physiology. High concentrations of dissolved salts reduce the water potential of the rooting medium, making water uptake physiologically difficult despite the presence of abundant water. At the same time, excessive uptake of Na^+ and Cl^- may cause ionic toxicity, disturb nutrient balance and interfere with metabolic processes. Mangroves have consequently evolved a complex suite of mechanisms that enable them to regulate salt uptake, maintain cellular water status and prevent toxic ion accumulation (Scholander *et al*., 1962; Parida & Jha, 2010).

Importantly, mangroves should not simply be regarded as plants that require high salinity. Different species possess different salinity tolerances, and their growth and distribution are determined by interactions among salinity, inundation, freshwater supply, nutrients and other environmental factors. Krauss *et al*. (2008) emphasized that mangrove seedling establishment is particularly sensitive to the interaction of these environmental drivers.

2. Salinity as an Environmental Stress

Salinity imposes both osmotic and ionic stress on mangrove plants. Increasing concentrations of salts in the soil or sediment decrease external water potential and therefore make water extraction by roots increasingly difficult. At the cellular level, excessive Na^+ and Cl^- can disturb ion homeostasis and interfere with essential metabolic processes. The ability to maintain water balance and regulate ion concentrations is therefore fundamental to mangrove survival under saline conditions (Parida & Jha, 2010).

The response of mangroves to salinity is complex because salinity rarely occurs independently in natural coastal ecosystems. Mangrove seedlings simultaneously experience tidal inundation, hypoxia, changing nutrient availability, variable light and temperature, and fluctuating freshwater inputs. Consequently, plant responses observed under controlled salinity treatments may differ from responses under natural field conditions (Krauss *et al*., 2008).

3. Osmotic Stress and Water Relations

The first major challenge associated with salinity is osmotic stress. Increased salt concentration lowers the water potential of the surrounding soil or sediment, thereby reducing the gradient required for water movement into roots. Mangroves compensate for this condition by maintaining sufficiently low internal osmotic potential to facilitate continued water uptake.

One important mechanism is osmotic adjustment, in which plants accumulate inorganic ions and compatible organic solutes. Compounds such as proline, soluble sugars, amino acids and other low-molecular-weight metabolites contribute to maintenance of cell turgor without severely disrupting cellular biochemical reactions. Parida and Jha (2010) reviewed evidence showing that compatible solutes and changes in cellular osmotic potential are important components of mangrove salt tolerance.

Maintenance of water relations is particularly important because mangroves can experience physiological drought even when surrounded by water. This apparent contradiction arises because the high salt concentration of the external environment decreases the availability of water to plant roots. Consequently, salinity tolerance requires coordinated regulation of water uptake, transpiration and cellular osmotic potential (Scholander *et al*., 1962; Parida & Jha, 2010).

4. Root-Level Salt Exclusion

One of the most important strategies used by mangroves is salt exclusion at the root level. Roots do not allow all ions present in the surrounding saline environment to enter the xylem indiscriminately. Instead, selective barriers and membrane transport systems regulate the movement of Na^+, Cl^- and other ions into the vascular system.

The classical work of Scholander *et al*. (1962) demonstrated the remarkable ability of mangroves to regulate salt balance despite exposure to seawater. Their work provided an important physiological foundation for subsequent research into mangrove salt tolerance.

Parida and Jha (2010) subsequently synthesized evidence showing that root-level salt exclusion represents one of the major mechanisms by which mangroves restrict excessive salt

accumulation in photosynthetically active tissues. The effectiveness of this mechanism differs among species, and it is often complemented by salt secretion and intracellular sequestration.

5. Ion Compartmentation and Cellular Salt Tolerance

When salts enter mangrove tissues, plants must prevent toxic concentrations from accumulating in the cytoplasm. One strategy is ion compartmentation, whereby excess Na^+ and Cl^- are transferred into vacuoles or other relatively tolerant cellular compartments.

Vacuolar sequestration reduces the concentration of toxic ions in the cytoplasm while simultaneously contributing to osmotic adjustment. This allows cells to maintain water uptake and turgor without exposing sensitive metabolic enzymes to excessive ionic concentrations (Parida & Jha, 2010).

The ability to regulate intracellular Na^+ is closely associated with membrane transport processes, including Na^+/H^+ antiport systems. Such transport mechanisms help maintain cytoplasmic ion homeostasis by moving Na^+ away from sensitive cellular compartments. Consequently, ion compartmentation represents a major cellular component of mangrove salinity tolerance.

6. Maintenance of Ion Homeostasis

Salinity tolerance requires plants to maintain an appropriate balance between essential ions and potentially toxic ions. In particular, maintaining an appropriate K^+/Na^+ balance is essential because excessive Na^+ can interfere with potassium-dependent metabolic processes.

Mangroves regulate ion movement through selective membrane transport, intracellular sequestration and controlled redistribution among tissues. Parida and Jha (2010) highlighted the importance of ion transport, Na^+/H^+ antiport mechanisms and ion compartmentation in mangrove salt tolerance.

At the whole-plant level, salt regulation can therefore be conceptualized as:

External salinity → selective root uptake → controlled ion transport → exclusion/secretion/sequestration → maintenance of cytoplasmic ion balance.

This integrated regulation allows mangroves to maintain metabolic activity despite continuous exposure to saline conditions.

7. Morphological and Anatomical Adaptations

Mangroves possess distinctive morphological and anatomical characteristics that contribute indirectly to their tolerance of saline and waterlogged environments. These include

specialized root systems, thick leaves, succulence and mechanisms associated with water conservation.

Mangrove root systems include pneumatophores, prop roots, stilt roots, knee roots and other specialized structures. Although these structures are particularly associated with anchorage and aeration under waterlogged conditions, they are also important components of the overall adaptation of mangroves to the combined stresses of salinity and inundation.

Mangrove seedlings are especially vulnerable because successful establishment requires simultaneous tolerance of salinity, flooding and changing sediment conditions. Krauss *et al*. (2008) therefore emphasized that seedling establishment should be considered in the context of multiple interacting environmental drivers rather than salinity alone.



Fig: Mangrove forest

8. Oxidative Stress and Antioxidant Defense

High salinity can disturb cellular metabolism and increase the formation of reactive oxygen species (ROS). Excessive ROS may damage lipids, proteins, pigments and nucleic acids. Mangroves therefore require efficient antioxidant systems to maintain cellular redox balance.

Important antioxidant enzymes include:

- Superoxide dismutase (SOD),
- Catalase (CAT),
- Ascorbate peroxidase (APX),
- Peroxidase (POD), and
- Glutathione-related enzymes.

Parida and Jha (2010) included antioxidant metabolism among the major biochemical mechanisms associated with mangrove responses to salinity.

The antioxidant response is particularly important because mangroves experience combinations of environmental stresses. Salinity may interact with high irradiance, temperature, drought and nutrient limitation, potentially increasing oxidative pressure beyond that caused by salinity alone.

9. Salinity and Photosynthesis

Salinity can negatively affect photosynthesis through changes in water relations, stomatal conductance, nutrient availability and cellular metabolism. When salinity reduces the plant's ability to acquire water, stomata may close, thereby reducing CO_2 diffusion into leaves. Prolonged or severe salinity can subsequently influence photosynthetic machinery and plant growth.

However, mangrove species differ in their physiological sensitivity to salinity. Some species maintain relatively high physiological performance under saline conditions, whereas others show stronger reductions in growth and photosynthetic activity as salinity increases. Therefore, species-specific responses are important when interpreting mangrove zonation and restoration success (Krauss *et al*., 2008).

10. Salinity and Mangrove Seedling Establishment

The seedling stage is particularly important for mangrove population dynamics because successful transition from propagule to established seedling determines future recruitment. Salinity can influence germination, establishment, growth and survival, but its effects are strongly modified by flooding, sediment conditions, nutrients and temperature.

Krauss *et al*. (2008) reviewed these interactions and concluded that mangrove establishment cannot be understood from salinity alone. The authors emphasized that both regional environmental factors and site-specific factors interact to determine seedling survival and growth.

This has important implications for restoration because simply selecting a salt-tolerant species does not guarantee successful establishment. Appropriate hydrological and sedimentary conditions are equally important.

11. Salinity and Mangrove Zonation

Salinity contributes to spatial variation in mangrove community composition. Species possessing more effective salt-exclusion, salt-secretion or ion-compartmentation mechanisms may occupy environments where less tolerant species experience physiological limitations.

Nevertheless, mangrove zonation is not controlled exclusively by salinity. Tidal inundation, elevation, sediment characteristics, nutrient availability, freshwater inputs and interspecific competition can modify the influence of salinity. Krauss *et al*. (2008) therefore described mangrove establishment and early development as responses to multiple interacting environmental drivers.

Consequently, observed differences in species distribution along coastal gradients should be interpreted using a multifactorial ecological framework rather than attributing zonation solely to salt concentration.

12. Mangroves and Coastal Environmental Regulation

The relationship between mangroves and salinity is not purely one-directional. While salinity influences mangrove distribution and physiology, mangrove vegetation can also modify coastal environmental conditions.

Dense root systems slow water movement and trap sediments, while plant growth and organic matter accumulation influence sediment structure and hydrological processes. Mangrove forests also provide coastal protection and other ecosystem services. Krauss *et al*. (2008) emphasized the broad ecological and societal importance of mangrove ecosystems, including their role in coastal protection and ecosystem functioning.

Mangrove soils additionally contribute to long-term carbon storage, making these ecosystems important components of coastal carbon cycling. Thus, maintaining mangrove forests has implications extending beyond salinity tolerance to broader climate and coastal-management objectives.

13. Salinity Under Climate Change

Climate change may modify mangrove salinity regimes through changes in sea level, rainfall, freshwater discharge, evaporation and coastal hydrology. In areas experiencing reduced freshwater inputs or prolonged drought, salinity may increase and potentially exceed the physiological tolerance of some species.

At the same time, responses to climate change will vary among locations and species because mangrove establishment depends on interactions among salinity, flooding, temperature, nutrients and other environmental factors (Krauss *et al*., 2008).

Therefore, future assessments should examine combined environmental stresses rather than treating salinity as an isolated climate-change factor.

14. Molecular Basis of Salinity Tolerance

Recent research has increasingly focused on the molecular mechanisms underlying mangrove salt tolerance. Important processes include regulation of ion transporters, Na^+/H^+ antiport systems, stress-responsive genes, antioxidant pathways and cellular signaling.

The molecular response can be represented as:

Salinity perception → cellular signaling → ion transport regulation → osmotic adjustment → antioxidant response → restoration of cellular homeostasis.

Parida and Jha (2010) highlighted molecular and genetic attributes alongside morphological, anatomical, physiological and biochemical mechanisms in explaining mangrove salt tolerance.

Future transcriptomic, proteomic, metabolomic and epigenetic studies are likely to improve understanding of how these mechanisms interact and why different mangrove species exhibit different salinity tolerances.

15. Mangroves as Models for Salt-Tolerance Research

Mangroves represent valuable natural models for understanding plant adaptation to salinity. Their ability to survive under saline conditions provides an opportunity to investigate mechanisms of salt exclusion, ion transport, osmotic adjustment, antioxidant defense and cellular protection.

Information obtained from mangrove species may contribute to broader plant-stress research, including the development of salt-tolerant crops. However, direct transfer of mangrove mechanisms to crop plants requires careful consideration because mangroves possess specialized anatomical and physiological characteristics that are absent in most agricultural species.

The long history of physiological research beginning with studies such as Scholander *et al*. (1962), followed by comprehensive reviews such as Parida and Jha (2010), provides an important foundation for current molecular and biotechnology-based investigations.

16. Implications for Mangrove Conservation and Restoration

- Understanding salinity tolerance has direct applications for mangrove restoration. Restoration projects should consider local salinity, tidal regime, elevation, freshwater availability, sediment characteristics and species-specific ecological requirements.
- Krauss *et al*. (2008) emphasized the importance of understanding environmental constraints on seedling establishment for reforestation and restoration activities.

- Therefore, successful restoration should not rely exclusively on planting large numbers of seedlings. Instead, restoration should seek to restore the hydrological and ecological conditions that permit natural recruitment and long-term forest development.

17. Research Gaps and Future Perspectives

- Despite substantial progress, several important questions remain.
- First, species-specific physiological thresholds for salinity tolerance need to be better quantified. Second, more long-term field experiments are required because short-term physiological responses may not accurately represent long-term adaptation. Third, greater attention should be given to root–soil–microbe interactions and their contribution to salt regulation.
- Fourth, molecular studies need to connect gene expression with measurable physiological traits. Finally, climate-change experiments should investigate combinations of salinity, drought, heat, flooding and elevated atmospheric CO_2 rather than evaluating these stresses individually.
- The multifactorial nature of mangrove establishment identified by Krauss *et al*. (2008) provides a strong conceptual basis for such future research.

Conclusion

Mangroves have evolved an exceptional capacity to survive saline environments through the integration of salt exclusion, salt secretion, ion compartmentation, osmotic adjustment, antioxidant defense and molecular regulation. The classical work of Scholander *et al*. (1962) established the importance of salt regulation in mangroves, while subsequent research has demonstrated that salinity tolerance is a complex trait involving multiple physiological and biochemical mechanisms.

Parida and Jha (2010) demonstrated that mangrove salt tolerance encompasses morphological, anatomical, physiological, biochemical, molecular and genetic characteristics rather than a single adaptive mechanism. Meanwhile, Krauss *et al*. (2008) showed that salinity must be considered alongside flooding, nutrients, temperature, light and other environmental variables when explaining mangrove establishment and development.

Overall, mangroves provide an important natural model for studying plant adaptation to salinity. Improved understanding of their mechanisms of salt tolerance can contribute to

mangrove conservation, climate-resilient coastal restoration, saline-land management and future plant biotechnology.

References

Krauss, K.W., Lovelock, C.E., McKee, K.L., López-Hoffman, L., Ewe, S.M.L. & Sousa, W.P. (2008). Environmental drivers in mangrove establishment and early development: A review. *Aquatic Botany*, 89(2), 105–127.

Parida, A.K. & Jha, B. (2010). Salt tolerance mechanisms in mangroves: A review. *Trees, 24*, 199–217.

Scholander, P.F., Hammel, H.T., Hemmingsen, E.A. & Garey, W. (1962). Salt balance in mangroves. *Plant Physiology*, 37(6), 722–729.

Volume: 06 Issue No: 09

VISIT OF THE MANAGING DIRECTOR, NHB TO REVIEW NHB HI- TECH ROSE CULTIVATION PROJECTS IN KARNATAKA

Article ID: AG-V06-I09-87

B Raja

Deputy Director, NHB, Bangalore-560022, Karnataka, India

Introduction

As part of the field-level review of horticulture development initiatives Shri Kapil Meena, IAS, Managing Director, National Horticulture Board (NHB), visited three NHB-assisted Hi-Tech Rose Cultivation projects at Bolamaranahalli Village, Kasaba Hobli, Nelamangala Taluk, Bengaluru Rural District, Karnataka, on 5th September 2026.

The projects were established under protected cultivation with financial assistance from NHB during 2023–24. The visit was undertaken to review the implementation and functioning of the projects, utilization of infrastructure, production and marketing practices, financial performance and the impact of NHB assistance.



During the field visit, the Managing Director inspected the polyhouses and allied infrastructure and interacted with the project promoters regarding crop management, production, post-harvest management, marketing and profitability.

A notable feature of the visit was the **active participation of women entrepreneurs in technology-intensive commercial horticulture**. Smt. K. S. Lakhmi and her daughters, Smt. Swetha K and Smt. Santhoshi Kurada, are actively involved in the management and operation of the rose cultivation enterprises.

NHB-ASSISTED PROJECTS VISITED

Sl. No.	Project Promoter	Activity	Area under NHB Assistance	Bank Term Loan (Rs lakh)	NHB Subsidy (Rs lakh)
1	Smt. K. S. Lakhmi	Hi-Tech Rose Cultivation	5,940 sq. m.	70.98	35.00
2	Smt. Swetha K	Hi-Tech Rose Cultivation	10,000 sq. m. (2.50 acres)	132.65	56.00
3	Smt. Santhoshi Kurada	Hi-Tech Rose Cultivation	7,000 sq. m.	101.85	46.50
Total			**22,940 sq. m.**	**305.48**	**137.50**

The three projects together represent **22,940 sq. m.(5.74 acres)** of NHB-assisted protected cultivation, with total NHB back-ended subsidy assistance of **Rs 1.375 crore**.



All three projects were financed through term loans from **Bank of India, Hesaraghatta Branch, Bengaluru**.

PROJECT INFRASTRUCTURE

The projects have been established with modern protected cultivation infrastructure, including polyhouses, drip irrigation, horticultural equipment and water-management facilities.

Smt. K. S. Lakhmi hi tech rose project



- Protected cultivation area:
- **5,940 sq. m.**
- One polyhouse
- Drip irrigation, fertigation system and
- horticultural equipment
- Labour room
- Water harvesting pond: **1,711 cu. m.**
- **Project Started on** 19.11.2022
- Project completed: **15.05.2023**
- NHB subsidy: **₹35.00 lakh**

Smt. Swetha K hi tech rose project



- Area under NHB assistance:
- **10,000 sq. m**
- Two polyhouses
- Drip irrigation and
- farm equipment
- Grading and pack house
- Two borewells
- Two pre-cooling units with
- total capacity of **94 cu. m.**
- **Project Started** : 19.11.2022
- Project completed: **18.05.2023**
- NHB subsidy: **₹56.00 lakh**

Smt. Santhoshi Kurada hi tech rose project



- Area under NHB assistance:
- **7,000 sq. m.**
- Two polyhouses
- Drip irrigation and automation
- Horticultural equipment
- One borewell
- Water harvesting pond: approximately
- **509.76 cu. m.**
- **Project Started** 27.07.2023
- Project completed: **30.11.2023**
- NHB subsidy: **Rs 46.50 lakh**

FIELD VISIT AND INTERACTION

During the visit, the Managing Director inspected the protected cultivation structures crop conditions and supporting facilities and interacted with the promoters on production, crop management, harvesting, post-harvest handling, marketing and profitability.

The promoters informed that the units are **functioning satisfactorily and generating good returns** from commercial rose cultivation. Smt Lakshmi promoter reported an income of approximately **Rs 22 lakh per acre per annum**.



The harvested roses are mainly marketed through **International Flower Action Bangalore Ltd (IFAB), Bengaluru**.

The promoters stated that payments are received through online modes, facilitating timely and transparent realization of sale proceeds.

The promoters specifically acknowledged that **timely receipt of NHB subsidy helped reduce the financial and interest burden associated with the bank loans** and supported the establishment and smooth operation of the projects.

EXPANSION, EMPLOYMENT AND MARKET-ORIENTED PRODUCTION

A significant outcome observed during the visit was the expansion of rose cultivation beyond the NHB-assisted projects.



The NHB-assisted area of **22,940 sq. m. (approximately 5.67 acres)** has been supplemented by approximately **11.26 acres of additional polyhouse area established from the promoters' own funds**, taking the total area under rose cultivation to approximately **17 acres**.

The enterprise provides employment to around **155 persons**, contributing to local employment and livelihood generation. The major commercial rose varieties cultivated include **Taj Mahal, Rockstar, Jumilia, Nobles, Revival and Beach Avalanche** etc according to market requirements.





SUCCESS STORY – IMPACT OF NHB ASSISTANCE

The three projects present a **successful example of NHB-supported Hi-Tech protected cultivation translating into commercial expansion, income generation and employment creation**.

The intervention can be broadly illustrated as:

Plain land -- Bank loan -- Protected Cultivation Infrastructure – Rose Plantation-Commercial Production -- NHB Subsidy --Market Linkage – Profits – Expansion of Poly house project –Employment Generation

The promoters utilized NHB assistance for establishing technology-intensive protected cultivation infrastructure and subsequently expanded their operations through their own investment.



THE MAJOR OUTCOMES OBSERVED:

- ✓ **3 NHB-assisted Hi-Tech rose projects** established and operational.
- ✓ **22,940 sq. m.** covered under NHB assistance.
- ✓ **Rs 1.375 crore** of NHB subsidy assistance provided for above 3 projects.
- ✓ Area expansion from 5.74 acres to now **17 acres** under total rose cultivation, additional area established through promoters' own investment.
- ✓ Adoption of **polyhouses, drip irrigation with fertigation system, automation and water-management systems**.
- ✓ Availability of **grading, packing and pre cooling facilities** in the relevant project.
- ✓ Reported income of approximately **Rs 22 lakh per acre per annum**.
- ✓ Established market linkage with **IFAB, Bengaluru**.



- ✓ Employment generation for approximately **155 persons**.
- ✓ Active involvement of **women entrepreneurs** in commercial protected horticulture.

The promoters' decision to make additional investments and expand the protected cultivation area demonstrates the continued development of the enterprise beyond the original NHB-assisted projects.

OVERALL ASSESSMENT: The field visit revealed that all three NHB-assisted projects have been established and are operational, with the major infrastructure being utilized for commercial rose production.



The projects demonstrate the effective combination of **institutional financial assistance, modern protected cultivation technology, entrepreneurial initiative, market linkage and post-harvest management**.The expansion to approximately **17 acres**, reported income levels and employment generation of around **155 persons** indicate the wider economic impact of the enterprise.

The active involvement of women entrepreneurs further highlights the potential of NHB-supported protected cultivation to promote **women-led entrepreneurship and commercial horticultural development**.

CONCLUSION: The visit of Shri Kapil Meena, IAS, Managing Director, NHB, to the three NHB-assisted Hi-Tech Rose Cultivation projects in Bengaluru Rural District provided an opportunity to assess the implementation and field-level impact of NHB assistance.

The projects were found to be operational, with the protected cultivation infrastructure being utilized for commercial rose production. The promoters reported satisfactory performance and good returns and acknowledged the role of timely NHB subsidy in reducing the financial and interest burden associated with project financing.

The subsequent expansion of the enterprise to approximately **17 acres**, together with employment generation for around **155 persons**, demonstrates the potential for scaling up technology-based horticultural enterprises.

The Managing Director appreciated the commitment, entrepreneurial initiative and active participation of the women promoters and encouraged them to continue adopting improved technologies, scientific crop management, water utilization, quality-oriented production, strengthened post-harvest practices etc and the three projects therefore constitute a noteworthy success story of NHB-supported Hi-Tech protected cultivation, women entrepreneurship, technology adoption, income generation, employment creation and expansion of commercial horticulture**.**

Volume: 06 Issue No: 09

PHYSICOCHEMICAL PROPERTIES OF STINGLESS BEE HONEY: A REVIEW WITH SPECIAL REFERENCE TO *TETRAGONULA IRIDIPENNIS* (Hymenoptera:Apidae)

Article ID: AG-VO6-I09-88

[1] Esakki Pandi S [1] Srivarsan V [1] Sabarinath R [1] Jayakishan M [2]Aishwarya P and [3]Jayaraj J*

[1] Final year B.Sc. (Agri) (Hons.) students, [2] Teaching Assistant (Agrl. Entomology), [3] Professor (Agrl. Entomology), Agricultural College and Research, Institute, Tamil Nadu Agricultural University, Chettinad – 630 102, Sivagangai District, Tamil Nadu, India

* Corresponding Author: Jayaraj. J

Abstract

Stingless bee honey is an increasingly valued bee product with distinctive physicochemical, biochemical and functional characteristics. Unlike conventional *Apis mellifera* honey, stingless bee honey is generally characterized by relatively high moisture, greater acidity, lower viscosity and distinctive sugar, mineral, enzyme and phenolic profiles. These characteristics vary with bee species, floral source, geographical location, season, climate, colony management, maturity and storage conditions. In India, *Tetragonula iridipennis* is an important indigenous stingless bee with increasing potential for meliponiculture and honey production. Published studies have reported considerable variation in moisture, pH, free acidity, electrical conductivity, sugars, hydroxymethylfurfural (HMF), enzymes, minerals, phenolics and antioxidant activity. High moisture is a characteristic feature but can increase susceptibility to fermentation, making post-harvest handling important. Phenolic compounds and flavonoids contribute to the antioxidant potential of the honey, although in-vitro antioxidant activity should not be interpreted directly as therapeutic efficacy. Existing standards developed mainly for *A. mellifera* honey may not adequately reflect the natural characteristics of stingless bee honey. Species- and region-specific quality standards and standardized analytical methods are therefore required. This review summarizes the major physicochemical properties of stingless bee honey, with particular emphasis on *T. iridipennis* and its potential for Indian apiculture and rural entrepreneurship.

Keywords: Stingless bee honey, Meliponini, *Tetragonula iridipennis*, moisture, acidity, sugars, phenolics, antioxidants, honey quality

1. Introduction

Stingless bee honey has a characteristic sweet-sour taste, relatively fluid consistency and distinctive aroma. Its composition differs considerably from conventional *Apis mellifera* honey. A comprehensive review of 522 samples representing 67 stingless bee species from 12 countries reported generally higher moisture and acidity and lower sugar and enzyme levels than *A. mellifera* honey. Considerable variation was also observed in minerals, phenolic compounds, colour and other parameters. These findings indicate that stingless bee honey should be evaluated according to its own natural characteristics rather than solely against conventional honey standards. In India, *Tetragonula iridipennis* is one of the important stingless bee species associated with meliponiculture. Recent investigations from Kerala, Maharashtra and Assam have provided valuable information on its physicochemical and biochemical characteristics. Such information is important for developing quality standards, authentication procedures, storage technologies and value-added products.

2. Factors Influencing Honey Composition

The physicochemical properties of stingless bee honey are influenced by several interacting factors:

- Bee species and colony characteristics
- Floral and botanical origin
- Geographical location
- Temperature and relative humidity
- Season
- Honey maturity
- Colony management
- Natural microbial activity
- Harvesting and extraction practices
- Storage duration and temperature

Consequently, physicochemical values should generally be considered as **species-, location- and floral-source-dependent ranges**, rather than fixed characteristics.

3. Major Physicochemical Properties

3.1 Moisture and Water Activity

Moisture is one of the most distinctive properties of stingless bee honey. It is generally higher than in conventional ripe *A. mellifera* honey. Reported values vary widely depending on species and location. Recent Indian studies illustrate this variation. Assam *T. iridipennis* honey contained **22.75 ± 0.24% moisture**, compared with 20.92% in *A. cerana* and 20.68% in *A. mellifera*. In Maharashtra, moisture values of **16.53–19.79%** were reported. High moisture gives stingless bee honey its characteristic fluidity but may also promote fermentation by osmophilic yeasts. Water activity is therefore an important complementary quality parameter. Hygienic harvesting, moisture monitoring, suitable packaging and controlled storage are essential for maintaining shelf life.

3.2 pH and Free Acidity

Stingless bee honey is generally acidic, and acidity contributes to its characteristic sour flavour and microbial stability. Assam *T. iridipennis* honey had a pH of **3.11 ± 0.05**, compared with 4.50 in *A. cerana* and 4.38 in *A. mellifera*. Maharashtra samples recorded pH values of approximately **3.36–3.46**. Organic acids, particularly gluconic acid, contribute to honey acidity. Free acidity is affected by floral source, microbial activity and storage. Because acidity varies substantially between samples, it should be interpreted together with moisture and water activity.

3.3 Total Soluble Solids and Electrical Conductivity

Total soluble solids, usually expressed as °Brix, indicate the concentration of dissolved solids, especially sugars. Stingless bee honey generally has lower soluble solids than fully ripened *Apis* honey because of its greater moisture. Electrical conductivity (EC) is associated with minerals, organic acids and other ionizable substances. It is useful for characterization of botanical and geographical origin. Maharashtra *T. iridipennis* honey showed EC values of approximately **1.01–1.13 mS/cm**, whereas Assam samples showed about **0.53 mS/cm**, demonstrating considerable geographical variation.

3.4 Sugars and Carbohydrates

Sugars constitute the major solid fraction of honey. Fructose and glucose predominate, while sucrose, maltose and other oligosaccharides occur in smaller quantities. Assam *T. iridipennis* honey contained **71.05 ± 0.55% reducing sugars** and **2.03 ± 0.04% sucrose**, with a fructose/glucose ratio of approximately 1.24. Stingless bee honey is also notable for the

occurrence of **trehalulose**, a disaccharide that has attracted considerable research interest. Sugar profiles are influenced by floral nectar, bee metabolism and enzymatic conversion and may be useful in honey authentication and detection of adulteration. HPLC and other chromatographic techniques provide more reliable sugar characterization than simple total-sugar measurements.

3.5 Hydroxymethylfurfural (HMF)

HMF is widely used as an indicator of honey freshness and thermal or storage damage. It forms through sugar degradation, particularly under acidic and elevated-temperature conditions. Fresh *T. iridipennis* honey may contain very low HMF. Assam samples contained only **0.28 ± 0.01 mg/kg**. HMF increases with inappropriate heating and prolonged storage and should therefore be monitored during commercial processing.

3.6 Enzyme Activity

Honey contains enzymes derived from bees, nectar and associated biological processes. Diastase and invertase are commonly used in honey-quality assessment. In southern Kerala, *T. iridipennis* honey showed substantial diastase and invertase activity, with differences between upland and midland honey. Assam honey showed 19.63 ± 0.48 DN diastase activity. The lower enzyme activity often reported in stingless bee honey compared with *Apis* honey is another reason why direct application of conventional honey standards may be inappropriate.

4. Mineral Composition and Ash

Minerals originate mainly from nectar, pollen and plant/environmental sources. Potassium, calcium, magnesium and sodium are among the commonly detected elements, together with trace elements such as iron, manganese and zinc.Ash content provides an approximate measure of the inorganic fraction. Assam *T. iridipennis* honey contained **0.30 ± 0.02% ash**, compared with 0.22% in *A. cerana*. Mineral profiles can provide useful information on geographical and botanical origin. Advanced techniques such as ICP-OES and ICP-MS can provide detailed elemental fingerprints.

5. Colour, Viscosity and Sensory Characteristics

Colour ranges from light yellow to amber and dark brown depending on floral source, phenolics, minerals and storage conditions. Assam *T. iridipennis* honey was reported as **dark amber**, while *A. cerana* honey was dark brown and *A. mellifera* honey light brown in the same study. The higher moisture content of stingless bee honey generally results in lower viscosity and a more fluid consistency. Its characteristic sweet-sour taste distinguishes it from conventional

Apis honey. These sensory characteristics can contribute to its identity as a premium specialty honey.

6. Phenolic Compounds and Flavonoids

Phenolic compounds and flavonoids are important minor constituents of honey and are largely derived from plants. They include phenolic acids, flavonoids and their glycosides.Studies on *T. iridipennis* have demonstrated considerable phenolic content. Southern Kerala honey from upland regions contained approximately **879.84 mg catechol/kg total polyphenols** and **220.09 mg catechin/kg flavonoids** under the analytical conditions used.A recent Assam study reported **84.24 mg GAE/100 g total phenolics** and **21.20 mg QE/100 g flavonoids**. Differences between studies may arise from extraction procedures, analytical methods, reference standards, floral sources and geographical conditions. Therefore, numerical comparisons between studies should be made cautiously.

7. Antioxidant Activity

Stingless bee honey has attracted considerable attention because of its antioxidant potential. Phenolic compounds, flavonoids and other reducing substances contribute to antioxidant activity.

Frequently used laboratory assays include:

- DPPH radical-scavenging assay
- ABTS assay
- FRAP assay
- ORAC assay
- Total phenolic content
- Total flavonoid content

The available literature demonstrates substantial variation in antioxidant activity among species and locations. Recent Indian investigations have reported appreciable antioxidant activity in *T. iridipennis* honey. However, **in-vitro antioxidant activity should not be interpreted as direct evidence of therapeutic efficacy in humans**. Clinical investigations would be necessary before making specific health claims.

8. Proteins, Amino Acids and Proline

Although proteins and amino acids constitute only a small proportion of honey, they are useful for characterization. Proline is commonly evaluated as an indicator of honey quality and

maturity. Assam *T. iridipennis* honey contained **1,286.05 ± 2.24 mg/kg proline**, substantially higher than the values reported for the *Apis* honeys examined in the same study. Amino-acid profiling may therefore provide additional information for authentication and differentiation of honey from different bee species and geographical areas.

9. Comparative Profile of Indian Honey

Table 1. Selected physicochemical properties reported for Assam honeys

Parameter	***T. iridipennis***	***A. cerana***	***A. mellifera***	***A. dorsata***
Moisture (%)	22.75	20.92	20.68	19.00
Reducing sugars (%)	71.05	64.75	65.30	74.07
Sucrose (%)	2.03	10.84	9.58	BDL
Ash (%)	0.30	0.22	BDL	BDL
HMF (mg/kg)	0.28	BDL	BDL	2.04
Diastase (DN)	19.63	7.61	8.26	1.05
Proline (mg/kg)	1286.05	192.20	335.32	172.22
pH	3.11	4.50	4.38	4.49
EC (mS/cm)	0.53	0.60	0.18	0.37
Colour	Dark amber	Dark brown	Light brown	Brown

BDL = Below detection limit. Values are study-specific and should not be regarded as universal species standards.

10. Stingless Bee Honey versus *Apis mellifera* Honey

A global review and subsequent meta-analysis indicate several broad differences between stingless bee and conventional *A. mellifera* honey.

Characteristic	**Stingless bee honey**	***A. mellifera* honey**
Moisture	Generally higher	Generally lower
Acidity	Generally higher	Generally lower
Viscosity	Usually lower	Usually higher
Sugar concentration	Often lower	Generally higher
Enzyme activity	Often lower	Generally higher

Characteristic	Stingless bee honey	*A. mellifera* honey
Phenolic profile	Highly variable	Highly variable
Antioxidant activity	Variable, often appreciable	Variable
Fermentation risk	Relatively greater	Generally lower

These are general trends rather than universal rules because floral origin, climate and species strongly affect composition.

11. Quality Standards and Authentication

A major challenge in the commercialization of stingless bee honey is the lack of universally harmonized standards specifically designed for Meliponini honey. Conventional *Apis* honey standards may not adequately accommodate the naturally higher moisture and acidity of stingless bee honey. Application of such standards without modification may incorrectly classify genuine stingless bee honey as poor quality.

A future quality standard should incorporate:

Physical parameters: moisture, water activity, colour, viscosity and specific gravity.

Chemical parameters: pH, free acidity, electrical conductivity, ash, HMF and sugar profile.

Biochemical parameters: diastase, invertase, proline and proteins.

Functional parameters: phenolics, flavonoids and antioxidant activity.

Safety parameters: microbial quality, pesticide residues, heavy metals and adulteration.

Authentication can be strengthened through HPLC, GC-MS, LC-MS/MS, NMR, mineral fingerprinting, pollen analysis, DNA metabarcoding and chemometric approaches.

12. Research Priorities for India

India has considerable potential for systematic research on indigenous stingless bee honey, particularly *T. iridipennis*. Priority areas include:

1. Establishment of regional physicochemical reference ranges.
2. Characterization of honey from different floral sources.
3. Seasonal studies covering pre-monsoon, monsoon and post-monsoon periods.
4. Investigation of natural fermentation and associated microbiota.
5. Shelf-life and packaging studies.
6. Development of rapid adulteration-detection methods.
7. Mineral and phenolic fingerprinting for geographical authentication.

8. Standardization of analytical methods.
9. Development of species-specific quality standards.
10. Evaluation of potential for premium and value-added products.

A national database covering bee species, floral source, location and physicochemical characteristics would be particularly valuable for establishing Indian quality standards.

Conclusion

Stingless bee honey is a distinctive natural bee product with significant scientific and commercial potential. Its physicochemical characteristics differ from conventional *Apis mellifera* honey, particularly in terms of moisture, acidity, viscosity, sugar composition, enzyme activity and certain bioactive constituents. Indian studies on *Tetragonula iridipennis* have demonstrated considerable variation among geographical regions, while also revealing potentially useful characteristics such as high proline, phenolic compounds, flavonoids and antioxidant activity. High moisture remains an important technological consideration because it increases the possibility of fermentation and consequently requires appropriate post-harvest handling and storage. The available evidence indicates that stingless bee honey should not simply be evaluated using standards developed for *A. mellifera*. Instead, species- and region-specific quality criteria should be developed using integrated physicochemical, biochemical, microbiological and sensory parameters. For India, systematic characterization of *T. iridipennis* honey from different states and floral environments could support quality certification, geographical authentication, premium marketing and rural entrepreneurship. Combining physicochemical analysis with pollen studies, mineral profiling, metabolomics and molecular authentication would provide a strong scientific basis for the future development of stingless bee honey as a high-value specialty bee product.

References

1. Biluca, F.C., Braghini, F., Gonzaga, L.V., Costa, A.C.O. & Fett, R. (2016). Physicochemical profiles, minerals and bioactive compounds of stingless bee honey (*Meliponinae*). *Journal of Food Composition and Analysis*, 50, 61–69.
2. Chuttong, B., Chanbang, Y., Sringarm, K. & Burgett, M. (2016). Physicochemical profiles of stingless bee (*Apidae: Meliponini*) honey from South East Asia (Thailand). *Food Chemistry*, 192, 149–155.

3. Chuttong, B., Chanbang, Y., Sringarm, K. & Burgett, M. (2018). Physicochemical properties of stingless bee honey from around the globe: A comprehensive review. *Journal of Food Composition and Analysis*, 73, 91–102.
4. Divya, K.K., Amritha, V.S., Aparna, B. & Devanesan, S. (2018). Biochemical and antioxidant properties of honey from *Tetragonula iridipennis* (Smith) of Southern Kerala. *Indian Journal of Entomology*, 80(3), 1011–1016.
5. Gadge, S.S., et al. (2023). Physiochemical, biological, and therapeutic uses of stingless bee honey. *Frontiers in Sustainable Food Systems*.
6. Pote, C.L., et al. (2025). Biochemical, antioxidants, and mineral constituents of stingless bee honey. *Frontiers in Sustainable Food Systems*, 9.
7. Souza, E.A., et al. (2024). Antioxidant activity, physicochemical and sensory properties of stingless bee honey from Australia. *Foods*, 13, 1657.
8. Zaldivar-Ortega, A.K., et al. (2024). The physicochemical parameters, phenolic content, and antioxidant activity of honey from stingless bees and *Apis mellifera*: A systematic review and meta-analysis. *Antioxidants*, 13(12), 1539.
9. Das, S., et al. (2025). Comparative nutritional and antioxidant profiling of Assam honeys: unveiling the untapped bioactivity of stingless bee honey. *Frontiers in Nutrition*.
10. Stingless bee honey: Quality parameters, bioactive compounds, health-promotion properties and modification detection strategies. Trends in Food Science & Technology, 81, 37–50.

Volume: 06 Issue No: 09

AUGMENTED REALITY IN FOOD: ENHANCING DINING, RETAIL, AND MANUFACTURING

Article ID: AG-V06-I09-89

Sathiamoorthy V and Ravindra Naik*

ICAR-Central Institute of Agricultural Engineering, Regional Station, Coimbatore – 641 007, Tamil Nadu, India.

*Corresponding Author: Ravindra Naik

Introduction

Augmented reality (AR) is an innovative technology that seamlessly integrates computer-generated digital information into a user's physical environment in real time. Unlike virtual reality, which completely immerses the user in an artificial setting, AR is designed to enrich and expand upon our perception of the real world rather than replacing it entirely. To achieve this dynamic blending of physical and digital realms, AR relies on devices equipped with advanced cameras, depth sensors, and high-resolution displays. Users can experience this technology through everyday mobile devices, such as smartphones and tablets, or through specialized wearable hardware like smart glasses and dedicated headsets. These sophisticated devices continuously scan and capture the surrounding physical space, instantly projecting interactive digital content ranging from complex 3D models to high-definition images and informational videos directly into the user's field of view, creating a truly hybrid experience.

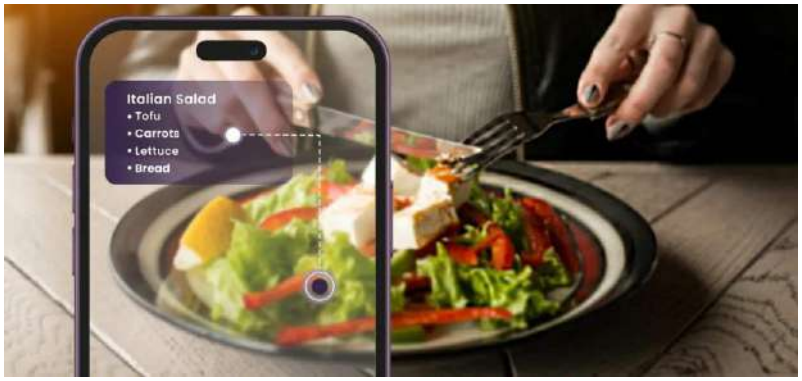


Fig. 1 Application of Augmented Reality in food

AR has entered the food and beverage industry, serving up a digital technology that is fundamentally changing how we order, prepare, shop for, and interact with our food. Far from being a fleeting gimmick relegated to smartphone games, AR is driving measurable improvements in customer engagement, operational efficiency, and food safety. By bridging the gap between the physical and digital worlds, AR is reshaping the culinary landscape from the factory floor to your kitchen table. Fig. 1 shows the application of augmented reality in food.

Rise of Augmented Reality

Originally popularized in gaming and entertainment, augmented reality has rapidly transitioned into a transformative tool across dining and food retail. Developing effective food-focused AR requires close collaboration between developers and designers to merge robust programming, intuitive interface design, and consumer insights, ensuring 3D dishes project seamlessly and interactively into real-world surroundings. Early industry adopters have capitalized on this to great effect: restaurants use QR-triggered 3D previews to elevate customer satisfaction and minimize order errors, while retailers animate packaging to share interactive nutritional and brand stories. Combined with virtual, chef-led culinary lessons, these applications fulfill consumer demand for convenience and transparency, ultimately deepening the connection between people and what they eat. The stepwise working of Augmented Reality in food restaurant chain is shown in the Fig.2 and Fig.3.

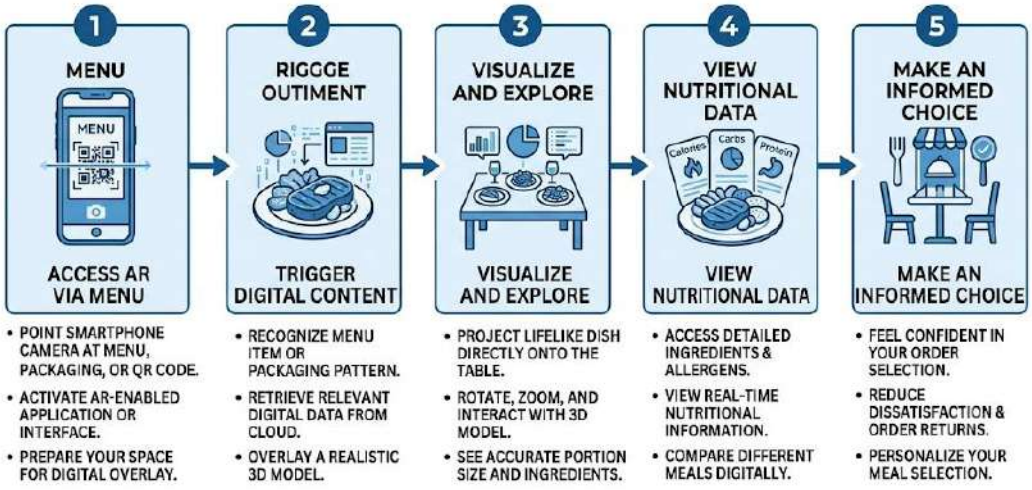


Fig.2 Working of Augmented Reality in food restaurants

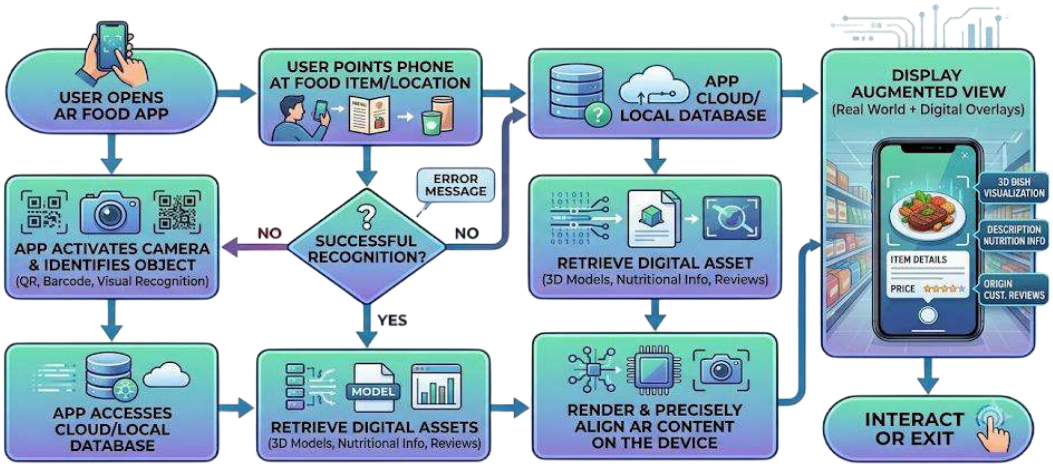


Fig.3 Stepwise working process of Augmented Reality in food application

Augmented Reality Trends in Food Application

Augmented reality is driving a wave of transformative trends across the food and beverage industry, comprehensively reshaping both consumer-facing experiences and critical back-of-house operations. In restaurants, flat menu photos are being rapidly replaced by interactive 3D visualizations; by simply scanning a QR code, diners can project hyper-realistic models of their prospective meals directly onto their tables, allowing them to accurately gauge portion sizes, ingredients, and plating aesthetics before committing to an order. This visual technology works in tandem with advanced allergy and nutrition tracking, empowering health-conscious patrons to overlay real-time macronutrient breakdowns, calorie counts, and customized allergen warnings directly onto their food choices to ensure a safe dining experience.

Beyond the restaurant environment, AR is fundamentally altering the grocery and retail sectors. Modern shoppers can point their smartphones at produce or packaged goods to access transparent supply chain data, instantly revealing farm origins, harvest dates, and a brand's eco-friendly practices. Similarly, consumer packaged goods companies are turning static boxes and beverage labels into dynamic marketing channels that unlock gamified experiences, immersive brand histories, and step-by-step preparation tutorials when scanned, extending customer engagement far beyond the point of purchase. Meanwhile, behind the kitchen doors, food service operators are deploying AR headsets and mobile simulations to modernize staff training. This immersive approach to onboarding allows new kitchen and waitstaff to practice complex food preparation techniques, familiarize themselves with station layouts, and master rigorous

sanitation protocols in a risk-free, virtual environment, thereby significantly cutting training time and reducing costly food waste.

AR headsets and tablets replace heavy manuals by projecting real-time digital checklists, safety protocols, and automated quality control inspections directly onto workstations, while also guiding chefs through precise culinary techniques to reduce human error. Simultaneously, AR transforms retail packaging into interactive marketing tools, enabling consumers to scan products and unlock immersive experiences like virtual distillery tours or step-by-step projected cooking instructions. This dual application not only ensures rigorous safety and hygiene standards, but also deepens consumer engagement, provides brands with valuable interaction data, and seamlessly merges our physical and digital culinary worlds.

Benefits of Integrating Augmented Reality in food

Integrating augmented reality into the food industry fundamentally redefines the culinary landscape, delivering profound, dual-sided benefits that empower both business owners and consumers. By blending physical dining with dynamic digital overlays, AR transforms the traditional acts of ordering, preparing, and consuming food into a highly interactive, transparent, and immersive ecosystem.

For restaurant owners and food retailers, AR serves as a powerful catalyst for operational efficiency and revenue growth. Behind the scenes, the technology significantly streamlines employee onboarding and compliance, replacing traditional manuals with virtual, hands-on simulations that teach complex preparation techniques and enforce rigorous food safety standards.



Fig.4. Usage of Augmented Reality in Restaurant

On the front end, offering customers 3D menu previews captures immediate attention, sets accurate expectations, and drastically reduces the rate of returned dishes due to

misunderstanding. Furthermore, these immersive experiences encourage diners to explore new menu items and premium add-ons, directly boosting average order values while fostering the kind of memorable brand connection that drives long-term customer loyalty. Fig. 4 depicts the usage of Augmented Reality in restaurants.

From a marketing standpoint, AR offers unparalleled innovation for food businesses. By transforming a standard meal into an engaging, interactive event, businesses organically generate highly shareable content.

When customers use their smartphones to reveal the farm-to-table journey of their ingredients or interact with virtual brand elements, they are eager to broadcast these novel experiences on social media, amplifying brand visibility and turning everyday meals into viral marketing moments. Fig.5 shows the role of Augmented Reality as marketing tool in a restaurant.



Fig.5 Augmented Reality as Marketing Tool

For consumers, AR entirely eliminates the guesswork and order anxiety traditionally associated with dining out. Diners are empowered with unprecedented visual clarity through hyper-realistic 3D previews of their meals, allowing them to accurately gauge portion sizes, ingredients, and presentation before committing to an order. Beyond aesthetics, AR provides critical nutritional insight and personalization. Diners can instantly access detailed macronutrient breakdowns, apply custom dietary filters tailored to specific allergies, and receive personalized recommendations based on their past preferences, ensuring every meal perfectly aligns with their health requirements and personal tastes.

Ultimately, AR elevates the consumer's role from passive diner to active participant in a broader culinary learning journey. The technology turns a standard dinner or grocery run into an educational adventure, offering on-demand insights into the origin of specific ingredients, the

history of regional cuisines, and the specialized techniques used by the chef. Coupled with faster, more accurate order processing, these augmented touchpoints ensure a dining experience that is not only highly efficient and personalized, but profoundly engaging.

Challenges in Augmented Reality implementation

Implementing augmented reality in the food industry presents substantial financial, technical, and operational hurdles. High initial development and ongoing maintenance costs often deter smaller businesses, especially when factoring in the expense of hiring specialized 3D artists and UX designers to produce quality content. Widespread adoption is further complicated by a steep learning curve for both staff and consumers, alongside the risk of launching in a market not yet accustomed to the technology.

Additionally, food businesses typically lack the in-house technical expertise required to ensure seamless cross-device compatibility, integrate AR platforms with existing restaurant management workflows, and maintain strict compliance with data privacy regulations.

Conclusion

Augmented reality has definitively moved beyond its origins in entertainment to become a foundational technology within the food industry, fundamentally altering how we interact with what we eat. By bridging the physical and digital worlds, AR empowers consumers with unprecedented transparency, offering everything from 3D menu previews and real-time nutritional overlays to immersive origin stories hidden within everyday packaging. For businesses, the technology provides a powerful dual advantage: it elevates front-of-house customer engagement and sales while simultaneously streamlining back-of-house operations through virtual training and rigorous safety protocols. While substantial hurdles remain ranging from high initial development costs and the need for specialized technical expertise to cross-device compatibility issues—the long-term trajectory is undeniable. As smart devices become more ubiquitous and AR interfaces grow increasingly intuitive, the friction of adoption will naturally decrease.

Ultimately, the integration of augmented reality into the culinary landscape is not a passing digital novelty, but a permanent evolution toward a more informed, efficient, and deeply personalized global food ecosystem.

Volume: 06 Issue No: 09

SUCCESS STORY ON CLUSTER DEMONSTRATION OF LINSEED AT RALEGAON BY AICRP ON LINSEED

Article ID: AG-VO6-I09-90

***Mrs. Snehal R. Vaidya, Mr. Nandkishor Tekale and Dr. Beena Nair**

All India coordinated Research Project on Linseed, College of Agriculture, Nagpur, India

*Corresponding Author: Mrs. Snehal R. Vaidya

Introduction and Farmer Profile:

The Chandrapur district and surrounding Vidarbha tracks are traditionally known as Massive Soybean growing regions during kharif (Monsoon). However, once the soybean crops are harvested, a vast majority of acreage historically sits completely idle for the remaining of the agriculture cycle.

Local Growers regularly struggled to establish secondary crops due to severe winter soil moisture loss, Minimal post-Monsoon irrigation access, heavy soil compaction and the high input expenditures required by conventional winter alternatives. To overcome this structural barrier, the All India coordinated Research Project on Linseed, Nagpur introduced systematic cluster interventions to prove that linseed functions as the ultimate profitable sequence crop following a soybean harvest.

Technological Intervention and Sowing:

To bridge the regional technology deficit, Scientists implemented extensive Cluster Frontline Demonstration. The primary objective centered on deploying a specialized high-yielding linseed variety PKV NL 260, directly into harvested soybean fields under both rainfed and irrigated environments aiming to raise the oilseed area across all 11 districts of the Vidarbha region, specifically targeting Chimur, Nagbhid, and Chandrapur District, and Umred in Nagpur. These technologies are demonstrated in the farmer's field under the guidance and supervision of a team of scientists who have developed them. ICAR-Indian Institute of Oilseeds Research, Hyderabad has been allocating demonstrations under Schedule cast Sub Plan (SCSP), Tribal Sub Plan (TSP) and Front line demonstrations to AICRP on Linseed, College of Agriculture, Nagpur.

AICRP on Linseed, College of Agriculture, Nagpur has conducted Cluster demonstrations at Chimur, Nagbhid and Sindewahi, Tahsil of Chandrapur District and Ramtek, UmredTahsil of Nagpur District.

Field Activities and Capacity Building:

The cluster demonstration on Linseed were conducted by AICRP on Linseed at farmers field of Mahatma phule ShetkariUtpadak sangh, Ralegaon, Tq. Warora , Di. Chandrapur from 2024 to 2026 in soybean growing area under rainfed and Irrigated Condition. During *rabi*2025-26, a total 110 demonstrations were conducted at Ralegaon village Tahsil warora, District Chandrapur. And State department of Agriculture and Mahabeej seed production Programme contribute the linseed area upto 400 Acres. For this One day training program entitled "Improved package of practices for linseed in Eastern Vidarbha" were conducted at Ralegaon on dated 04-11-2025 in this training programme technical guidance are provided to the farmers from Land preparation to seed treatment and sowing .

Training are conducted at the actual site of sowing in the farmer's field and monitoring of the demonstration plot is done on a regular basis When the crop is in flowering stage, a Field day was conducted at the farmer's field. A Field day in this regard was conducted on 23, january 2026 at Ralegaon village. Approximately 150 farmers had attended the program. The university provided 100% grant for an oil mill which was installed by a Mahatma Phule Shetkari Utpadak Sangh in year 2024-2025 at village Ralegaon.





Measurable Results and Media Impact:

The Cluster Frontline Demonstration on Linseed during 2025-2026 created a significant impact on adoption rates. In comparison to the 2024-2025 season, the area under Linseed increased from 28.32 ha to 161.87 ha. Due to visible success of Front Line Demonstration which demonstrated a 70% increase over the previous year.





This expansion was directly credited to the demonstration of improved variety and better management practices, which convinced nearby farmers to adopt the technology to enhance their productivity. The success of the cluster demonstration was credited to significant yield and area increase, which generated Media attention. The impact was notably covered by the regional channel Doordarshan features the success story of two farmers and Field Day programme of Linseed and telecast it on dated 11/02/2026 and 01/04/2026 on Amchi Mati Amchi Manasa. programme on Doordarshan. This media coverage shows "social impact" and "wide scale awareness.

Volume: 06 Issue No: 09

MICROGREENS AS FUNCTIONAL HORTICULTURAL CROPS: NUTRITIONAL QUALITY, PHYTOCHEMICAL POTENTIAL AND SCOPE FOR SUSTAINABLE PRODUCTION

Article ID: AG-V06-I09-91

Dr. K. Sha

Regional Research Station, TNAU, Viruthachalam, Tamil Nadu-606001, India

Introduction

Microgreens have emerged as an important group of functional horticultural crops because they combine a short production cycle, compact growing habit, attractive appearance, distinctive flavour and considerable nutritional value. They are young edible seedlings of vegetables, herbs, legumes and selected other crops, generally harvested when the cotyledons are fully developed and the first true leaves begin to appear. Recent literature commonly describes the harvest period as approximately 7–21 days after germination, although the exact stage varies with species, temperature, light, growing medium and production system.

Unlike conventional vegetables that require a relatively long period to reach marketable maturity, microgreens can produce a harvestable product within a few weeks. This characteristic makes them particularly attractive for urban horticulture, protected cultivation, indoor farming, terrace gardens, kitchen gardens and controlled-environment agriculture. Their small size also allows production where land availability is limited. Recent research has highlighted their compatibility with soil-based, soilless and controlled-environment production systems and their potential role in diversified urban food systems.

The nutritional importance of microgreens is associated not only with vitamins and minerals but also with a diverse group of phytochemicals. Depending on species and growing conditions, these include phenolic compounds, flavonoids, carotenoids, chlorophylls, glucosinolates and other antioxidant-related compounds. However, their concentration is not uniform among crops, and nutritional composition can change considerably according to genotype, growing medium, nutrient management, temperature, light intensity, light spectrum

and harvest stage. Therefore, microgreens should be viewed as a diverse group of horticultural crops rather than as a single nutritionally uniform commodity.



Diversity of Microgreens

A major advantage of microgreens is their wide crop diversity. Species belonging to Brassicaceae, Fabaceae, Amaranthaceae, Apiaceae, Lamiaceae and Poaceae are commonly investigated for microgreen production. Radish, mustard, broccoli, cabbage, kale, pak choi, fenugreek, pea, sunflower, amaranth, beetroot, basil, coriander and wheat are examples of crops that can be cultivated at the microgreen stage. Each crop provides a different combination of colour, flavour, texture, growth habit and nutritional characteristics.

Brassicaceae microgreens, particularly broccoli, radish, mustard, kale and cabbage, have received considerable research attention because of their phenolic compounds, vitamins and glucosinolates. Glucosinolates can give Brassica microgreens their characteristic pungent flavour, and their breakdown products, including isothiocyanates and indoles, are an important area of nutritional research. The concentration of these compounds is influenced by genotype and cultivation conditions. Legume-based microgreens such as pea and fenugreek provide another group with distinctive nutritional and culinary characteristics. Pea shoots are valued for their tender texture and mild flavour, while fenugreek microgreens have a characteristic aroma and taste. Sunflower microgreens are also popular because of their larger cotyledons, crunchy texture and attractive appearance. Amaranth and beet microgreens provide red or purple pigmentation associated with plant pigments and phytochemical diversity.



This diversity creates an opportunity for growers to produce mixed microgreen products rather than depending on a single crop. A combination of green, red, purple and yellow-green microgreens can improve the visual quality of salads and other foods while increasing the diversity of plant-derived nutrients.

Nutritional Importance of Microgreens

The nutritional potential of microgreens is one of the major reasons for their increasing research and commercial interest. Studies have reported the presence of vitamins such as vitamin C, vitamin E and vitamin K, along with minerals including potassium, calcium, magnesium, iron and zinc. However, nutrient concentration varies significantly among species and production systems, so values from one microgreen should not be generalized to all microgreens. Microgreens are particularly interesting from a phytochemical perspective. Phenolic acids and flavonoids contribute to antioxidant capacity, while carotenoids and chlorophylls contribute to pigmentation and are associated with plant nutritional quality. Brassica microgreens additionally contain glucosinolates, while coloured microgreens can contain anthocyanins and related pigments. These compounds are being investigated for their biological activities, although the health effects of consuming specific microgreens in humans require careful interpretation and cannot automatically be inferred from laboratory studies.

An important feature of microgreens is that the nutritional profile of a crop can change during plant development. Research on different growth stages has shown that some minerals and phytochemicals can be concentrated at the microgreen or seedling stage, while other compounds change as the plant develops. Consequently, harvest timing is an important management factor when the objective is to obtain a particular nutritional profile. The often-repeated claim that microgreens universally contain many times more nutrients than mature vegetables should be treated cautiously. Research demonstrates substantial nutritional differences among species, but the magnitude of these differences depends on the nutrient measured, crop, cultivar and growing conditions. Therefore, scientific communication should emphasize **nutrient density and phytochemical diversity** rather than applying one fixed nutritional superiority value to every microgreen.

Phytochemical Properties and Functional Food Potential

The functional-food potential of microgreens is closely associated with their secondary metabolites. Phenolic compounds, flavonoids, carotenoids, anthocyanins and glucosinolates are among the major groups investigated. These compounds participate in plant defence and pigmentation and may also possess antioxidant or other biological activities. Brassica microgreens are particularly important because their glucosinolate profile can be influenced by environmental and agronomic factors. Research has demonstrated that substrate, fertilization and artificial lighting can modify phytochemical composition. This provides an important opportunity for horticultural scientists to develop production practices that enhance desirable nutritional characteristics without compromising yield and quality.

The term “functional horticultural crop” is therefore appropriate when microgreens are considered not simply as miniature vegetables but as crops that can contribute nutrients and bioactive plant compounds to the diet. Nevertheless, it is scientifically important to distinguish between the presence of bioactive compounds and proven clinical health effects. Current research supports considerable phytochemical potential, but many health-related claims remain dependent on laboratory, experimental or observational evidence rather than large-scale human intervention studies. A 2026 review also emphasizes the need for further standardization and validation when translating microgreen bioactives into functional foods.

Production Technology

Microgreens can be produced using relatively simple materials. A shallow food-grade tray, suitable growing medium, quality seed, water and adequate light are sufficient for small-scale production. Cocopeat, seed-starting mixtures and other clean soilless substrates are commonly used. Hydroponic and other controlled systems can also be adopted when precise management of water and nutrients is desired.



Seed quality is particularly important because microgreens are generally harvested at a very young stage. Seeds intended for edible microgreen production should be clean, healthy and free from unsuitable chemical seed treatments. Uniform germination results in a more uniform canopy and harvest. For small seeds such as broccoli and mustard, appropriate sowing density is essential, whereas larger seeds such as pea and sunflower require different management.

The growing medium should provide adequate moisture retention, drainage and aeration. Excessive moisture can create conditions favourable for microbial growth and poor root development. Insufficient moisture, on the other hand, can reduce germination and produce uneven stands. Clean water and hygienic production practices are therefore essential because microgreens are commonly consumed fresh and often without a cooking step. Light is another major factor controlling microgreen growth and quality. Natural sunlight can be used for small-scale production, whereas LED lighting is increasingly employed in controlled environments. Recent research indicates that light intensity, spectrum and photoperiod can influence biomass production as well as the accumulation of phenolics, flavonoids, carotenoids, vitamins and glucosinolates. The response, however, is species dependent.

Recent controlled-environment research has consequently moved beyond simply maximizing biomass. The objective is increasingly to achieve a balance between yield,

appearance, nutritional quality, phytochemical concentration, energy consumption and postharvest life. This represents an important research direction for future microgreen production systems.



Harvesting and Postharvest Management

Harvesting is generally carried out when the microgreens reach the desired stage of development. Clean scissors or harvesting tools can be used to cut the shoots above the growing medium. Harvest timing affects texture, appearance and biochemical composition. Early harvesting may produce tender material, whereas delayed harvesting can change leaf development, stem characteristics and phytochemical profiles.



Because microgreens contain delicate tissues and high moisture content, postharvest handling is important. Clean harvesting equipment, hygienic handling, rapid cooling where

appropriate and suitable packaging can help maintain quality. Research indicates that processing methods such as drying, blanching and juicing can alter antioxidant and phytochemical profiles. Minimal processing generally provides better opportunities for retaining sensitive compounds, although the appropriate method depends on the intended product. Food safety deserves particular attention. The warm and humid conditions required for germination can also favour microbial growth if sanitation and water quality are poorly managed. Trays, growing media, seeds, irrigation water, harvesting equipment and packaging materials should therefore be handled hygienically. Food safety should be integrated into the production system from seed selection through harvesting and marketing.

Microgreens and Urban Horticulture

Microgreens are particularly suited to urban and peri-urban horticulture because they require little space and have a short production cycle. They can be produced on balconies, terraces, windowsills, protected structures and indoor racks, provided suitable environmental conditions are maintained. Vertical production allows several trays to be arranged in tiers, increasing production per unit floor area.

This characteristic has implications for nutrition as well as horticultural entrepreneurship. Households can produce small quantities for fresh consumption, while entrepreneurs can develop commercial systems supplying restaurants, hotels, supermarkets and direct consumers. Recent reviews identify controlled-environment microgreens as a potential component of weather-resilient and urban crop production because of their short crop duration and adaptability to soil-less systems. For Indian conditions, microgreens can complement rather than replace conventional vegetable production. Their greatest advantage lies in providing a rapid, high-value, space-efficient crop that can be produced close to consumers. Small farmers, self-help groups, youth entrepreneurs and urban gardeners may explore microgreen production where there is reliable market demand and access to clean production facilities.

Scope for Research and Value Addition

Microgreens provide a wide field for horticultural research. Studies can compare species and cultivars for germination percentage, plant height, fresh yield, dry matter, leaf area, colour, chlorophyll, carotenoids, total phenolic content, flavonoids, antioxidant activity, vitamin content and mineral composition. Such research can help identify crops suitable for different production environments. Nutrient management is another promising research area. The influence of organic

nutrient sources, mineral nutrition, biofertilizers, micronutrients and controlled nutrient solutions can be evaluated for their effects on growth and nutritional quality. Biofortification with selected minerals may also be investigated, provided that safe and scientifically validated application levels are used.

Lighting research offers additional opportunities. LED intensity, spectrum and photoperiod can be evaluated for their effects on growth, pigment accumulation and phytochemical production. Recent 2026 research emphasizes that manipulating light can be used to influence both biomass and secondary metabolism, opening opportunities for producing microgreens with targeted quality characteristics. Value addition is another emerging area. Fresh microgreens can be incorporated into salads, sandwiches, soups, vegetable preparations, smoothies and other foods. Research is also examining microgreen powders, extracts and functional food ingredients. However, processing should be designed carefully because heat, oxygen, light and prolonged storage may reduce some sensitive phytochemicals. Current research is moving towards improved extraction, stabilization and encapsulation technologies for microgreen-derived bioactive compounds.

Future Prospects

The future of microgreens lies in integrating horticulture, nutrition, controlled-environment technology and food science. The next generation of production systems is likely to focus not simply on producing more biomass but on producing **consistent, safe and nutritionally characterized microgreens**. Genotype × environment interactions, precise nutrient management, LED lighting, automated irrigation, sensor-based environmental control and vertical farming are promising areas for further investigation. Recent 2026 research also points towards AI-assisted environmental management, biofortification and environmentally responsible packaging as emerging areas for improving consistency and reducing postharvest losses. These developments could help transform microgreens from a niche horticultural product into a more systematically managed functional crop.

Conclusion

Microgreens represent an innovative category of functional horticultural crops with considerable potential for nutritional diversification, urban food production and value-added horticulture. Their short production cycle, small space requirement, attractive appearance and diverse phytochemical composition make them suitable for both household and commercial

production. Their nutritional and phytochemical profiles, however, vary substantially with crop, genotype and production conditions, making scientific production management essential.

The future research agenda should therefore concentrate on identifying superior genotypes, optimizing growing media and nutrient management, developing efficient LED-lighting protocols, improving food safety, extending postharvest shelf life and establishing reliable nutritional standards. Rather than considering microgreens simply as miniature vegetables, they can be developed as precision-grown functional horticultural crops designed to provide diverse nutrients and plant bioactive compounds within compact production systems.

Volume: 06 Issue No: 09

FOOT-AND-MOUTH DISEASE: A CONTINUING THREAT TO LIVESTOCK HEALTH AND PRODUCTION

Article ID: AG-VO6-I09-92

Shiva Jyothi

Department of Veterinary Biotechnology, College of Veterinary Science, PVNRTVU Rajendranagar, Hyderabad, India

Introduction

Foot-and-mouth disease (FMD) is one of the most contagious and economically important viral diseases of livestock. It affects cattle, buffaloes, pigs, sheep, goats and other cloven-hoofed animals and is capable of spreading rapidly through herds, villages, regions and even across international borders. Although adult animals usually survive the infection, the disease can cause severe losses through reduced milk production, weight loss, reproductive problems, lameness, mortality in young animals and restrictions on the movement and trade of livestock and animal products. Because of its ability to spread rapidly and its enormous economic consequences, FMD remains one of the most important transboundary animal diseases in the world. FMD continues to be a global concern despite decades of vaccination and disease-control efforts. The recent re-emergence of FMD in parts of Europe during 2025 and the spread of the SAT1 serotype beyond its traditional geographical range have again demonstrated how quickly the disease can challenge livestock health and international trade. In 2026, FAO and WOAH have continued to emphasize enhanced surveillance, preparedness, laboratory capacity, biosecurity and appropriate vaccination strategies in regions at risk of SAT1 introduction.

Etiology

Foot-and-mouth disease is caused by **foot-and-mouth disease virus (FMDV)**, a small, non-enveloped, positive-sense single-stranded RNA virus belonging to the genus *Aphthovirus* of the family *Picornaviridae*. The virus exists as seven immunologically distinct serotypes: **O, A, C, SAT 1, SAT 2, SAT 3 and Asia 1**. One of the most important characteristics of FMDV is that immunity against one serotype does not reliably protect against another serotype. Even within a

serotype, considerable antigenic variation may occur, making the selection of appropriate vaccine strains an important part of disease control. The virus is highly infectious and can be transmitted through direct contact with infected animals as well as through contaminated feed, water, equipment, vehicles, clothing and other fomites. Infected animals may release virus in saliva, nasal secretions, milk, faeces and other secretions. Pigs can produce particularly large quantities of virus through respiratory secretions, while cattle are highly susceptible and can become important amplifiers of infection. Sheep and goats may show comparatively mild or less obvious clinical disease and can therefore contribute to the silent spread of infection.

Pathogenesis

After entering a susceptible animal, FMDV initially replicates at the site of entry, particularly in tissues of the upper respiratory tract or pharyngeal region. The virus rapidly multiplies and spreads through the bloodstream, producing viraemia and disseminating to tissues with suitable cellular receptors. The virus has a particular affinity for epithelial cells, where extensive viral replication results in cellular degeneration and formation of characteristic fluid-filled vesicles.

The most recognizable lesions develop in the **mouth, tongue, dental pad, feet and teats or mammary glands**. Viral replication within epithelial tissues causes separation of the superficial epithelial layers from underlying tissues, resulting in vesicle formation. These vesicles eventually rupture, leaving painful erosions. Infected animals may therefore have difficulty eating, drinking and walking. In dairy animals, lesions on the teats can interfere with milking and predispose to secondary bacterial mastitis. The outcome of infection varies with the animal species, age, immune status and virus strain. Young animals are particularly vulnerable to severe disease because FMDV can affect cardiac muscle, producing **myocarditis** and sudden death. This is one reason why mortality can be much higher in young calves, lambs and kids than in adult animals. Adult animals generally recover, but production losses may continue long after the visible lesions have disappeared.

Clinical Signs

The clinical picture of FMD can vary according to the species and viral strain, but the disease often begins with fever, depression, reduced appetite and a sudden decline in production. In dairy cattle and buffaloes, a rapid fall in milk yield may be one of the earliest indications that something is wrong within the herd. Soon after the onset of fever, characteristic vesicles may

appear inside the mouth, on the tongue, dental pad and lips. These vesicles may rupture rapidly, producing painful erosions. Animals may salivate excessively, producing the classic **"roping" or stringy salivation** associated with FMD. They may smack their lips, have difficulty eating and show reluctance to drink because of oral pain. Lesions on the feet are another important feature. Vesicles may develop around the coronary band and in the interdigital spaces. After rupture, the affected area becomes painful, and animals may develop severe lameness. Cattle may repeatedly shift their weight from one leg to another, hesitate to walk or remain lying down for prolonged periods. In dairy animals, vesicles and erosions may occur on the teats and udder. These lesions can make milking painful and may increase the risk of secondary bacterial infection and mastitis. Pregnant animals may experience reproductive disturbances, while young animals can develop severe myocardial damage. In sheep and goats, clinical disease may be much less dramatic. Mild lameness or small oral lesions may be the only obvious signs. This makes small ruminants particularly important from a surveillance perspective because animals that appear only mildly affected can still participate in transmission.

Diagnosis

Clinical suspicion is extremely important, but **clinical signs alone cannot confirm FMD**. Several other diseases can produce vesicles, erosions, salivation or lameness, including other vesicular diseases. WOAH specifically emphasizes that FMD cannot be reliably distinguished clinically from several other vesicular conditions, making urgent laboratory confirmation essential whenever FMD is suspected. Samples such as vesicular epithelium, vesicular fluid and appropriate swabs or other specimens should be collected according to approved veterinary diagnostic protocols and submitted to an authorized laboratory. Molecular methods such as **real-time RT-PCR** can detect viral RNA rapidly, while antigen detection and virus isolation may be used for confirmation and characterization. Molecular characterization is particularly important because identifying the circulating serotype and lineage helps veterinary authorities determine whether available vaccines are likely to provide appropriate protection. Recent WOAH guidance emphasizes continued virus characterization and genotyping to monitor viral evolution and support evidence-based vaccination and control decisions.

Treatment

There is no specific antiviral treatment that eliminates FMDV from infected livestock, and treatment should never delay official disease-control measures. Because FMD is a major

transboundary animal disease, any suspected outbreak should be immediately reported to the appropriate veterinary authority. Supportive care may be provided under veterinary supervision to maintain hydration, nutrition and animal welfare. Soft feed may be useful for animals with painful oral lesions, while clean and comfortable housing can reduce additional stress. Foot lesions should be managed carefully to reduce secondary bacterial infection and further trauma. Dairy animals may require careful attention to milking hygiene and udder health. However, treatment of individual animals is not the central strategy in an FMD outbreak. The primary objective is to stop transmission, identify infected premises and prevent the virus from reaching additional herds. Early detection and rapid response are therefore far more important than attempting to cure individual animals. WOAH has emphasized that rapid detection and response are essential when FMD occurs in previously free regions.

Control and Prevention

Control of FMD requires a coordinated approach involving vaccination, surveillance, movement control, biosecurity, laboratory diagnosis and rapid outbreak response. Because the virus spreads so efficiently, controlling animal movement is particularly important. Movement of infected or exposed cattle, buffaloes, sheep, goats and pigs can rapidly transport the virus to new areas. Informal movement of small ruminants is also a recognized risk because sheep and goats may carry and spread the virus while showing limited clinical signs.

Vaccination remains one of the most important tools for FMD control. However, FMD vaccination is more complicated than vaccination against many other livestock diseases because immunity is serotype- and strain-dependent. Vaccine formulations therefore need to contain antigenically appropriate strains that match the viruses circulating in the region. Regular vaccination alone, however, cannot guarantee control if other biosecurity measures are neglected. New animals should be managed carefully before introduction into a herd, unnecessary animal movement should be avoided, equipment should not be shared between farms without appropriate cleaning and disinfection, and visitors should follow farm biosecurity procedures. Vehicles, footwear, clothing, livestock markets and animal gathering points can all become important pathways for disease transmission. Early recognition by farmers is equally important. A sudden fall in milk production, excessive salivation, mouth lesions, lameness or blisters around the feet and teats should never be ignored. Farmers should avoid moving suspected animals and immediately contact veterinary authorities. Attempting to transport an infected

animal to another farm, market or veterinary facility can unintentionally spread the disease over a much wider area.

Recent global events have reinforced the importance of preparedness. Germany reported FMD in January 2025 after decades without an outbreak, while subsequent outbreaks occurred elsewhere in Europe. Germany regained WOAH recognition as free from FMD without vaccination in April 2025 after successful containment. At the same time, SAT1 emerged as a major concern in parts of the Near East and West Eurasia, demonstrating that FMD serotypes can move beyond their historically recognized geographical patterns. In 2026, FAO has continued to warn countries in Asia and the Pacific about the risk associated with SAT1 and has called for increased vigilance and preparedness. This highlights an important lesson: **FMD control cannot stop at national borders**. Regional cooperation, information sharing, coordinated surveillance and harmonized control measures are essential for managing a virus that can move rapidly through interconnected livestock populations.

The Economic Impact

The importance of FMD extends far beyond the clinical disease seen in individual animals. A single outbreak can affect an entire livestock economy. Milk production may fall dramatically, animals may lose body condition, young animals may die, fertility may be affected and farmers may face additional costs for veterinary care, vaccination and biosecurity. The greatest economic consequences may occur indirectly through restrictions on animal movement and trade. Countries and regions affected by FMD may face restrictions on the export of livestock and animal products. For smallholder farmers, particularly those who depend heavily on cattle, buffaloes, sheep, goats or pigs for income and food security, an outbreak can have serious consequences for household livelihoods. WOAH describes FMD as one of the world's most economically destructive livestock diseases because of its effects on food security, rural livelihoods and international trade.

Conclusion

Foot-and-mouth disease remains one of the most important challenges facing livestock health worldwide. It is a highly contagious viral disease capable of spreading rapidly among susceptible animals and across geographical boundaries. Although adult animals generally survive, the disease can cause severe production losses, painful lesions, lameness, reproductive problems and death in young animals. The continuing evolution and movement of FMDV make

surveillance and preparedness essential. The recent spread of SAT1 into regions where it was previously uncommon has demonstrated that the global FMD situation can change rapidly. Recent FAO and WOAH recommendations therefore emphasize early detection, rapid laboratory confirmation, virus characterization, appropriate vaccination, strong biosecurity, movement control and coordinated regional response. For farmers, the message is simple: **recognize the signs, do not move suspected animals and contact the veterinarian immediately**. For veterinary professionals, early suspicion, rapid reporting, appropriate sampling and strict biosecurity are essential. For animal-health authorities, sustained vaccination, surveillance and preparedness are the foundation of long-term control. FMD may be caused by a microscopic virus, but its consequences can reach farms, communities, national economies and international trade. The most effective way to fight it is therefore not to wait for an outbreak, but to build strong **vaccination, surveillance and biosecurity systems before the virus arrives**.

References

1. World Organisation for Animal Health (WOAH). **Foot and mouth disease**. Paris: WOAH; updated 2025–2026.
2. World Organisation for Animal Health (WOAH). **Foot and mouth disease: Infection with foot and mouth disease virus. Terrestrial Animal Health Code, Chapter 8.8.** Paris: WOAH.
3. World Organisation for Animal Health (WOAH). **Chapter 3.1.8. Foot and mouth disease (infection with foot and mouth disease virus). Biological Standards Commission report.** Paris: WOAH; 2025.
4. Food and Agriculture Organization of the United Nations (FAO). **Foot-and-mouth disease: Animal diseases and recent situation updates.** Rome: FAO; 2025–2026.
5. FAO. **Rapid risk assessment: foot-and-mouth disease virus serotype SAT1.** Rome: FAO; 4 March 2026.
6. FAO. **FMD Serotype SAT1 alert: Situation update and recommendations for prevention, preparedness, and response in the Near East and West Eurasia.** Rome: FAO; 8 May 2025.
7. World Organisation for Animal Health (WOAH). **The State of the World's Animal Health 2025: Foot-and-mouth disease—A global threat to livestock and trade.** Paris: WOAH; 2025.

8. World Organisation for Animal Health (WOAH). **FMD: Managing the response amidst media chaos during a recent resurgence.** Paris: WOAH; 13 June 2025.
9. World Organisation for Animal Health (WOAH). **WOAH calls for action on foot-and-mouth disease (SAT1) international spread.** Paris: WOAH; 2026.
10. World Organisation for Animal Health (WOAH). **Foot and mouth disease: vaccine information and control recommendations.** Paris: WOAH; 2025.

Volume: 06 Issue No: 09

MUGA SILK: THE GOLDEN TREASURE OF ASSAM

Article ID: AG-VO6-I09-93

Jeevanandham S [*1], Priyadharshini P[2] and Thangamalar A[3]

[1] Research Fellow, Department of Sericulture, Forest College and Research Institute, TNAU, Mettupalayam, Tamil Nadu, India.

[2] Assistant Professor, Department of Sericulture, Forest College and Research Institute, TNAU, Mettupalayam, Tamil Nadu, India.

[3]Teaching Assistant, Department of Sericulture, Forest College and Research Institute, TNAU, Mettupalayam, Tamil Nadu, India.

*Corresponding Author: Jeevanandham S

Abstract

Muga is a golden silk produced only in Assam by the semi domesticated silkworm *Antheraea assamensis*. This article describes the natural colour and durability of the fibre, the som and soalu trees that feed the silkworm, and the hand reeling that turns cocoons into yarn. It also covers the history of muga under the Ahom kings, the weaving cluster at Sualkuchi and the Geographical Indication status granted in 2007. National production was only about 261 metric tonnes in 2022 to 2023, limited by disease, loss of host plants and a narrow genetic base. The article ends with the interest in muga fibroin for biomedical use and the work needed to keep muga production going. Assam gives the world many things, tea, one horned rhinos, and the Brahmaputra river. It also gives the world a silk that no other place can produce. This is muga, a golden silk found only in Assam. People in the state have worn it for generations, and it still carries a special place in Assamese homes today.

Introduction

Muga silk comes from a wild silkworm called *Antheraea assamensis*. This insect lives only in Assam and a few nearby hill areas of Northeast India (Tikader et al., 2013). Almost all of the world's muga silk, close to the entire amount, is produced in Assam alone. No other state and

no other country produces it in any meaningful quantity. The silk has a natural golden yellow colour. This colour is not added through dye. It comes directly from the fibre itself. Weavers never bleach or dye muga cloth, because doing so would destroy the very quality that makes it valuable. With every wash, the golden shine becomes brighter and richer. A muga garment often looks better after years of use than it did on the day it was bought. This is one reason muga cloth gets passed down from mothers to daughters as a family possession. The fabric is also known for its strength. It resists wear far better than ordinary silk, which is why old muga sarees and chadors survive for decades without falling apart. People in Assam sometimes say a good muga saree can outlast the person who first wore it, and pass safely into the hands of a grandchild.

The Silkworm Behind the Silk

Unlike the mulberry silkworm, which is fully domesticated and depends completely on human care, the muga silkworm is still largely wild. Farmers do not control its breeding the way they do with mulberry silkworms. This makes muga a semi domesticated insect, somewhere between a wild species and a farmed one. The silkworm feed mainly on the leaves of two trees, som and soalu. Som is known by the botanical name *Persea bombycina*, and soalu is *Litsea polyantha*. Farmers grow these trees in their yards and along field borders specifically to raise muga silkworms. Without healthy som and soalu trees, there is no muga silk. In Assam, host plant cultivation for muga now covers more than four thousand hectares of land, spread across many districts.

The muga silkworm goes through the usual insect stages, egg, larva, pupa and adult moth, but it repeats this cycle several times within a single year. Scientists describe this as a multivoltine life cycle, with roughly four to five generations completed annually. Each stage responds strongly to the length of daylight, which changes with the seasons. This gives farmers more than one rearing season a year, but it also means the insect faces a wider range of weather conditions and disease risks across those months. One striking fact about this silkworm is how sensitive it is to its surroundings. It cannot tolerate polluted air or heavily disturbed environments. This sensitivity has kept muga rearing tied to certain pockets of Assam where the air and vegetation remain relatively undisturbed.

From Cocoon to Cloth

Turning a muga cocoon into finished yarn takes real skill. Each cocoon holds a single continuous filament that can run several hundred metres in length. To free this filament, workers

first boil the cocoons in an alkaline solution made from plant ash. This step removes the natural gum holding the fibres together and strips away the outer floss. The actual reeling is done on a simple pedal operated device called a Bhir. Two people usually work together at one Bhir, carefully drawing out and twisting the filament from several cocoons at once. It takes thousands of cocoons, often somewhere between four and five thousand, to produce just one kilogram of raw muga silk. This hand reeling process is part of why muga yarn remains costly and why mass production has never fully replaced traditional methods.

Muga differs here from eri, the other well known silk of Assam. Eri cocoons are open mouthed, since the moth is allowed to leave the cocoon before processing. Because the fibre is not one continuous strand, eri cannot be reeled. It is instead spun much like cotton, using a simple hand spindle. Muga, along with mulberry and tasar silk, belongs to the group of silks that are reeled rather than spun. This difference in processing is one reason muga yarn has the smooth strength that spun eri yarn does not.Once the yarn is ready, weavers use fly shuttle looms, often fitted with jacquard or dobby attachments for patterns. Some weavers dye the yarn to even out its colour, though the golden tint of natural muga is rarely covered completely.

A Legacy From the Ahom Kings

Muga silk has a long history in Assam. Its association with royalty grew strong during the rule of the Ahom dynasty, which governed the region from 1228 to 1826. Under Ahom patronage, muga weaving grew from a household craft into an industry connected with status and identity. The kingdom is known to have overseen the farming, reeling and weaving of both muga and eri silk as part of its administration. The fabric became closely linked with nobility, and for a long period ordinary people had limited access to it. Over time, muga moved beyond the royal court and became part of everyday Assamese culture, especially during festivals and weddings. Even today, a muga mekhela chador is considered a mark of pride at Bihu celebrations and other important occasions in Assam.

Sualkuchi, the Weaving Heart of Assam

Most of the finished muga cloth in Assam comes from a village called Sualkuchi, located a short distance from Guwahati. Generations of weavers there have turned raw muga yarn into sarees, mekhela chadors and other garments. Because of its scale and skill, Sualkuchi is often described as the centre of the Assam silk industry, covering muga, eri and mulberry silk together.

In Sualkuchi, weaving is not treated as a separate trade practiced only by a few families. It runs through nearly the entire village, with looms present in most homes. One detailed survey of the Sualkuchi weaving cluster counted well over twenty thousand active looms across the area, supporting tens of thousands of people once weavers, helpers and support staff are all counted. Many of these workers are women, and weaving has long been an important source of independent income for them. Visitors to Sualkuchi can watch the full process, from handling raw yarn to producing a finished piece of cloth ready for market.

Recognition and Protection

Because muga silk is unique to Assam, the state sought legal protection for it. The Assam Science Technology and Environment Council applied for Geographical Indication status for muga, and the tag was granted in 2007 (Kalita, 2022). A separate GI logo for muga was issued in 2014, giving buyers a way to check that a product is genuine muga silk from Assam and not an imitation from elsewhere.

The Central Silk Board also plays a role in protecting and developing muga silk. It inspects muga products, certifies authenticity, and supports research through the Central Muga Eri Research and Training Institute at Lahdoigarh in Jorhat, Assam. This institute works on issues ranging from silkworm health to yarn quality. State schemes have also tried to organise muga production more efficiently. Under a cluster plantation approach started in the mid 2000s, the government grouped traditional silk growing families in certain blocks and assigned different roles across the production chain, some as commercial rearers, others as seed cocoon growers, and others running small scale grainage units for egg production. Families taking part received financial help for planting host trees and setting up basic equipment. Government estimates suggest close to twenty eight thousand families across Assam are now engaged in some part of muga cultivation, from tending host trees to rearing silkworms.

The Struggle to Survive

Despite its value, muga silk faces real threats. National figures show total muga silk production in India was around 261 metric tonnes in the 2022 to 2023 financial year (Central Silk Board, 2023), a small figure compared to the tens of thousands of tonnes produced from mulberry silk each year across the country. This gap shows how limited and fragile muga production remains. Disease is one of the biggest problems. A condition called pebrine, caused by microsporidian parasites, can spread through a muga silkworm population and destroy an

entire batch of cocoons. Farmers have reported significant losses to this disease over the years (Tikader et al., 2013), and it remains difficult to control because the muga silkworm is not raised under the same closed, controlled conditions as mulberry silkworms.

Loss of host plants adds to the pressure. Som and soalu trees need space and stable growing conditions. As land use changes and forest cover shrinks in parts of Assam, farmers find it harder to maintain enough host trees to support large scale rearing. The insect's sensitivity to pollution and disturbed habitats further narrows the areas where muga can still be reared successfully. Because of these combined pressures, disease, habitat loss and a naturally narrow genetic base within the species (Arunkumar et al., 2012; Tikader et al., 2013), muga silk production has not grown at the pace many hoped for, even as demand for it continues both within India and abroad.

A Fabric With Global Reach

Muga silk is not only an Assamese fabric. It travels well beyond the state, and even beyond India. Japan has long been a buyer of muga silk, using it in quilts, curtains and fine kimono fabric. Within India, muga is worked into sarees, umbrellas, bed covers and upholstery, in addition to its traditional role in the mekhela chador. This mix of local ritual use and international demand keeps muga relevant both as heritage and as trade. Researchers at institutions such as the Indian Institute of Technology Guwahati have also studied muga fibroin, the core protein in muga silk, for possible use in biomedical applications such as tissue engineering (Kasoju et al., 2009). This shows that muga silk still holds unexplored value well beyond textiles.

Future perspectives

Protecting muga means protecting more than a fabric. It means protecting a specific insect species, the trees it depends on, and the weaving knowledge passed down through families in places like Sualkuchi. Continued work on disease management, host plant cultivation and silkworm breeding will decide whether muga silk remains a living tradition in Assam or slowly fades into something rare enough to see mainly in museums. For now, muga silk still holds its place as one of Assam's clearest symbols. It carries the state's history, its relationship with its own forests, and the skill of its weavers, all in a single strand of golden thread.

Conclusion

Muga silk depends on a narrow set of conditions. It needs one silkworm species, two main host trees and parts of Assam where the air and vegetation stay relatively undisturbed. Its golden colour, durability and place in Assamese culture sustain demand, yet output remains small because of pebrine, shrinking host plant cover and low genetic variation among populations. Studies on wild populations have found one group in the West Garo Hills of Meghalaya that differs clearly from the others (Arunkumar et al., 2012), and such populations deserve further study for conservation and breeding. Better disease control, more host tree plantations and continued support for the weaving families of Sualkuchi are the practical steps that would give muga production a better chance of growing.

References

Arunkumar, K. P., Sahu, A. K., Mohanty, A. R., Awasthi, A. K., Pradeep, A. R., Urs, S. R., and Nagaraju, J. (2012). Genetic diversity and population structure of Indian golden silkmoth (Antheraea assama). *PLoS ONE*, 7(8), e43716. https://doi.org/10.1371/journal.pone.0043716

Central Silk Board. (2023). Production volume of muga silk in India from financial year 2008 to 2023 (in metric tons). Statista. https://www.statista.com/statistics/1025429/india-production-volume-muga-silk/

Kalita, P. (2022). Role of Muga Silk GI of Assam in the sustainable development of Assam. *International Journal of Law Management & Humanities*, 5(6), 588 to 598. https://www.ijlmh.com/wp-content/uploads/Role-of-Muga-Silk-Gi-of-Assam-in-the-Sustainable-Development-of-Assam.pdf

Kasoju, N., Bhonde, R. R., and Bora, U. (2009). Preparation and characterization of Antheraea assama silk fibroin based novel non-woven scaffold for tissue engineering applications. *Journal of Tissue Engineering and Regenerative Medicine*, 3(7), 539 to 552. https://doi.org/10.1002/term.196

Tikader, A., Vijayan, K., and Saratchandra, B. (2013). Muga silkworm, Antheraea assamensis (Lepidoptera: Saturniidae): an overview of distribution, biology and breeding. *European Journal of Entomology*, 110(2), 293 to 300. https://www.eje.cz/pdfs/eje/2013/02/26.pdf

Volume: 06 Issue No: 09

FOREST MENSURATION: THE NUMBERS BEHIND NATURE'S HIDDEN WEALTH

Article ID: AG-V06-I09-94

S. Akash[1*], Dr. R. Ravi[1] and A. Asha[1]

[1] Forest College and Research Institute, Tamil Nadu Agricultural University, Mettupalayam, Tamil Nadu – 641 301, India

*Corresponding Author : S. Akash

Abstract

Forest mensuration is the branch of forestry concerned with measuring the dimensions, volume, growth, and productivity of trees and forest stands. It provides the quantitative foundation for sustainable forest management, timber valuation, biomass estimation, carbon accounting, and biodiversity assessment. Traditional methods based on diameter, height, and form factor have evolved into sophisticated approaches incorporating laser scanning, remote sensing, drone photogrammetry, and artificial intelligence. Accurate estimation of tree volume is essential for determining sustainable yield, supporting national forest inventories, and meeting climate change mitigation goals through carbon stock assessment. Modern technologies such as LiDAR and terrestrial laser scanning offer greater precision and efficiency compared with conventional techniques. Despite these advances, challenges related to species variability, measurement errors, inaccessible terrain, and changing growth patterns remain. Forest mensuration thus serves as a vital link between mathematics, ecology, and technology, enabling informed decisions for the conservation and sustainable utilization of forest resources.

Keywords - Forest Mensuration, Tree Volume Estimation, LiDAR Technology, Carbon Stock Assessment, Sustainable Forest Management

1. Introduction: The Numbers Behind Nature

Walk into any forest — whether a misty mangrove in the Sundarbans, a towering deodar grove in Himachal Pradesh, or a dense sal forest in Odisha — and you are surrounded by wealth. Not the wealth locked in vaults, but natural capital measured in cubic metres of timber, tonnes of

absorbed carbon, and litres of stored water. Yet this immense value remains invisible to the naked eye unless we count, calculate, and measure. Forest mensuration is the science that makes this wealth legible. Derived from the Latin mensura (meaning measure), it is the branch of forestry concerned with determining the dimensions, volume, age, and growth of individual trees and entire forests. Far from being a dry academic exercise, it is the engine that powers sustainable timber harvesting, carbon credit markets worth billions of dollars, and national climate commitments under the Paris Agreement **(FAO, 2020)**.

2. Forest Mensuration: The Science of Measuring Forests

Forest mensuration encompasses the measurement and assessment of forests in quantitative terms. It provides the data backbone for forestry practice, conservation planning, carbon accounting, and national resource inventories. At its core, it answers a deceptively simple question: How much is here, and how fast is it growing? The discipline has evolved dramatically. Early foresters in 18th-century Europe relied on felling trees and sectioning their trunks with hand tools — a destructive and laborious process. By the 20th century, optical instruments like clinometers and hypsometers allowed height measurement without cutting a single branch. Today, satellite imagery, drone photogrammetry, and artificial intelligence-powered point-cloud analysis allow scientists to map entire forest landscapes with centimetre-level accuracy without setting foot inside them.



3. Why Measuring Tree Volume Matters

Tree volume is perhaps the single most important figure in practical forestry. Here is why:

- Timber valuation: Sawmills, furniture manufacturers, and construction companies buy wood by volume. Accurate mensuration ensures fair pricing and prevents over-harvesting.

- Carbon accounting: Every cubic metre of wood is approximately 50% carbon by dry weight. Accurate volume estimates feed directly into national greenhouse gas inventories submitted to the UN Framework Convention on Climate Change (UNFCCC).
- Sustainable yield: Forest managers use volume data to set annual allowable cuts — the maximum timber that can be harvested without degrading the forest's long-term productivity.
- Biomass and bioenergy: Wood biomass is the world's largest source of renewable energy. Accurate volume underpins energy yield estimates.
- Biodiversity conservation: Volume and structural data reveal old-growth characteristics that host the greatest biodiversity.

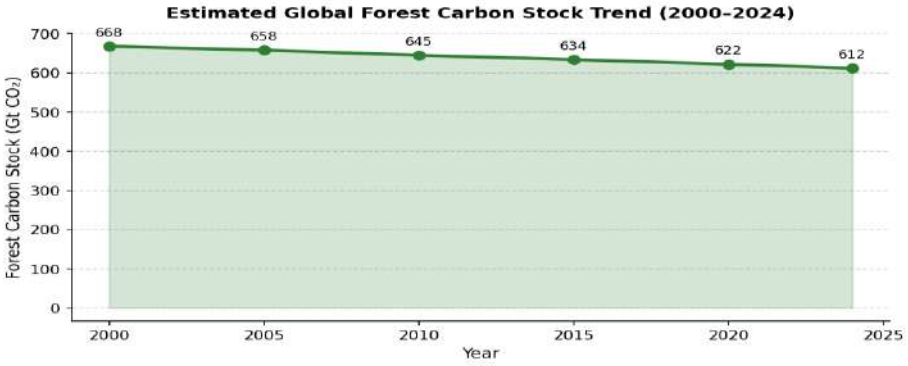
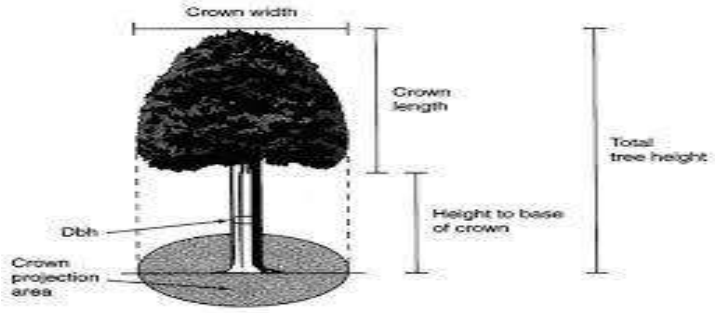


Figure 1. Estimated global forest carbon stock trend, 2000–2024. Data sources: FAO (2020), Global Forest Watch (2024).

4. Understanding Tree Volume: More Than Height and Diameter



4.1 What Is Tree Volume?

Tree volume refers to the amount of space (in cubic metres or cubic feet) occupied by the solid woody material of a tree — primarily the stem or bole, and sometimes branches. It is not the same as mass or weight, though the two are related through wood density.

4.2 Types of Tree Volume

- Total volume: Volume of the entire tree above the stump, including all branches.
- Merchantable volume: The volume of commercially useful timber, up to a minimum top diameter.
- Stem (bole) volume: Volume of the main trunk only — the most commonly reported figure.
- Volume over bark (VOB): Includes the bark layer; used in standing tree assessments.
- Volume under bark (VUB): Excludes bark; more relevant for wood products.

4.3 Forest Wealth and Volume Estimation

India's forests alone store an estimated 7,124.6 million tonnes of carbon, according to the India State of Forest Report 2023 — a figure derived from extensive mensuration surveys. Globally, forests sequester about 2.6 billion tonnes of CO_2 annually, making accurate volume measurement not just economically important but existentially critical for climate stabilisation (India State of Forest Report, 2023; Global Carbon Project, 2023).

5. The Building Blocks of Volume Measurement

Three primary measurements feed into virtually every tree volume equation: diameter, height, and form factor.

5.1 Diameter at Breast Height (DBH)

DBH is measured at a standardised height of 1.3 metres above ground (in India and most of Asia; 1.37 m or 4.5 ft in North America). It is measured using a diameter tape (a circumference tape calibrated in diameter units) or precision calipers. DBH is the single most predictive variable for tree volume and is used in virtually every volume equation and table.

5.2 Tree Height

Three height measures are relevant: total height (ground to apex), merchantable height (ground to the point where the stem reaches minimum merchantable diameter), and crown height (base of live crown to apex). Heights are measured using clinometers, laser hypsometers, or — increasingly — LiDAR systems.

5.3 Form Factor

A perfect cylinder would have a form factor of 1.0. Real trees taper toward the crown, giving form factors between 0.3 and 0.7 depending on species, age, and site quality. The form factor

corrects volume estimates derived from DBH and height alone, accounting for stem taper. Species with high form factors (closer to a cylinder) yield more timber per unit height.

5.4 Basal Area

Basal area — the cross-sectional area of a tree at breast height — is calculated as $\pi(DBH/2)^2$. At the stand level, total basal area per hectare is a key measure of forest stocking and density.

6. Tools Used in Forest Mensuration

The mensuration toolkit has expanded enormously in recent decades. The table below summarises key instruments in use today.

Category	Instrument	Primary Use
Traditional	Diameter Tape	Measuring stem circumference / DBH
Traditional	Tree Calipers	Direct diameter measurement at any height
Traditional	Clinometer	Estimating tree height via angle trigonometry
Modern	Laser Rangefinder	Non-contact height and distance measurement
Modern	Terrestrial LiDAR (TLS)	3-D stem and canopy volume scanning
Modern	UAV / Drone	Aerial canopy mapping and volume estimation
Modern	Smartphone + AR App	Quick DBH and height via augmented reality

Table 1. Instruments used in forest mensuration, from traditional to modern. Sources: MDPI Remote Sensing (2024); ScienceDirect (2023).

A landmark 2024 review in MDPI Remote Sensing found that smartphones equipped with RGB cameras and LiDAR sensors (such as those in current Apple iPad Pro and iPhone Pro models) can now measure DBH with errors below 5 cm and height with errors below 1 m, bringing professional-grade mensuration to non-specialist field workers (MDPI, 2024).

7. Methods of Tree Volume Measurement

7.1 Direct Measurement Methods

The most accurate — but most destructive — approach involves felling the tree and measuring its sections. The stem is divided into logs of equal length L, and each section is measured at its

ends (Ab = basal area, At = top area) or mid-point (Am = mid-area). Three classical formulas are used:

- Huber's Method: V = Am × L — uses only the mid-section area. Simple and fairly accurate for regularly tapered stems.
- Smalian's Method: V = (Ab + At)/2 × L — uses the average of the two end areas. Can overestimate volume in strongly tapered stems.
- Newton's Method: V = (Ab + 4Am + At)/6 × L — uses all three measures. Mathematically most rigorous and is considered the 'gold standard' for sectional measurement.

7.2 Indirect Measurement Methods

Because felling every tree is both destructive and impractical, foresters developed indirect methods for standing trees. These use mathematical models, regression equations, and optical or laser instruments to estimate volume without harming the tree. Modern indirect methods include smartphone-based photogrammetry, handheld electronic dendrometers, and full-stand LiDAR scanning **(FAO, 2020)**.

8 .Modern Technologies Transforming Forest Measurement

The 21st century has brought a revolution in how we measure forests. Digital technologies are delivering faster, cheaper, and often more accurate results than traditional ground surveys.

Remote Sensing and Satellite Imagery

Satellite platforms such as Sentinel-2 (ESA) and Landsat 9 (NASA/USGS) provide multi-spectral data at 10–30 m resolution. Combined with machine learning models, these images can estimate forest biomass across entire continents. Global Forest Watch uses such data to track forest loss and gain in near real-time.

LiDAR Technology

Light Detection and Ranging (LiDAR) fires thousands of laser pulses per second through a forest canopy, creating three-dimensional point clouds that capture every branch and trunk. A 2026 study in Frontiers in Plant Science found that Terrestrial Laser Scanning (TLS) achieves DBH measurement error as low as 1.9 cm (RMSE = 0.019 m) — far exceeding manual methods. Mobile Laser Scanners (MLS) cover up to 50 m²/min compared to 0.43 m²/min for traditional surveys, dramatically improving field efficiency (Frontiers in Plant Science, 2026).

Unmanned Aerial Vehicles (Drones)

Drones equipped with RGB cameras or LiDAR sensors can survey inaccessible terrain, regenerating slopes, or dense forest understorey in hours. Structure-from-Motion photogrammetry algorithms stitch drone imagery into detailed 3-D forest models that rival ground-based surveys in accuracy.

Artificial Intelligence and Machine Learning

AI algorithms trained on thousands of measured trees can now predict volume from aerial imagery with accuracy comparable to field surveys. The 2024 national-scale modelling system released by the USDA Forest Service integrates AI-driven volume, biomass, and carbon models for every tree species in the United States (Westfall et al., 2024).

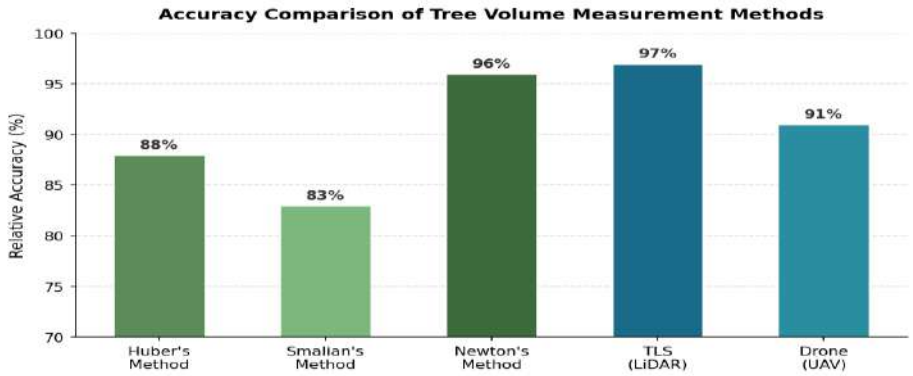


Figure 2. Relative accuracy (%) of traditional vs. modern tree volume measurement methods. Sources: Frontiers in Plant Science (2026); MDPI Remote Sensing (2024).

Method	Formula Used	Best For	Accuracy
Huber's Method	V = Am × L	Single log sections	High (~88%)
Smalian's Method	V = (Ab+At)/2 × L	Felled trees	Moderate (~83%)
Newton's Method	V = (Ab+4Am+At)/6 × L	All stem shapes	Very High (~96%)
TLS / LiDAR	3-D point cloud	Standing trees	Highest (~97%)
Drone (UAV)	Photogrammetry	Large-scale stands	High (~91%)

Table 2. Comparative overview of tree volume measurement methods and their accuracy.

9. Applications of Tree Volume Measurement

Accurate volume data underpins a remarkable range of real-world activities **(FAO, 2020; Forest Survey of India, 2023)** :

- Timber production and harvest planning: Setting annual allowable cuts and optimising log assortment.
- Carbon stock and biomass assessment: Feeding into REDD+ programmes and voluntary carbon markets.
- National forest inventories: Providing governments with the data to track forest resources and biodiversity.
- Forest certification: FSC and PEFC certification schemes require volume-based sustainability assessments.
- Research and policy: Informing silvicultural trials, endangered species habitat assessments, and climate models.

10. Challenges in Accurate Volume Estimation

Despite impressive technological progress, significant challenges remain **(Global Carbon Project, 2023; Forest Survey of India, 2023)**:

- Species variation: Tree form varies widely across species and sites. A volume table calibrated for teak in Madhya Pradesh may be unreliable for the same species in Kerala.
- Measurement error: Observer bias in reading calipers or clinometers can introduce systematic errors of 5–10% in volume estimates.
- Inaccessible terrain: Dense forests, steep slopes, and waterlogged areas limit both traditional and drone-based surveys.
- Outdated volume tables: Many regional tables in India and Southeast Asia were compiled in the 1950s–1970s and do not reflect current growth conditions under climate change.
- Climate change effects: Altered precipitation, temperature, and CO_2 levels are changing growth patterns, making historical allometric models less reliable.

11. The Future of Forest Mensuration

The convergence of precision forestry, digital twins, and connected sensor networks promises to transform how we monitor forests. Digital forest twins — virtual replicas of real forests updated in real time from sensor data — are already being piloted in Scandinavian countries. IoT-enabled dendrometers automatically transmit diameter growth data to cloud

platforms, allowing managers to track forest dynamics continuously rather than through periodic surveys. In India, the Forest Survey of India is expanding its use of multi-date satellite data and AI models to update its State of Forest Report on a more frequent basis. The integration of community-based forest monitoring — where trained local volunteers collect smartphone-based mensuration data — promises to bridge the gap between expensive high-tech surveys and the need for comprehensive ground-truthing t **(MDPI *Remote Sensing*, 2024; Westfall et al., 2024; *Frontiers in Plant Science*, 2026)**.

12. Conclusion: Revealing the Hidden Wealth of Forests

Forest mensuration stands at the intersection of mathematics, ecology, and technology — a quiet science whose importance is anything but quiet. Every timber contract, every carbon credit, every national climate report, and every forest conservation policy rests on the reliability of the measurements it provides. From Huber's mid-section formula scribbled in a 19th-century notebook to AI algorithms processing millions of LiDAR returns per second, the tools have evolved dramatically. Yet the fundamental insight has not changed: to protect forests, we must first know them — and to know them, we must measure them.

Behind every standing tree lies a story written not only in rings and leaves, but also in numbers that help safeguard the future of our forests. Forest mensuration gives us the language to read that story — and the wisdom to act on it **(FAO, 2020; Global Carbon Project, 2023; Forest Survey of India, 2023; MDPI *Remote Sensing*, 2024; Westfall et al., 2024; *Frontiers in Plant Science*, 2026)**.

References

Food and Agriculture Organization of the United Nations. (2020). *Global forest resources assessment 2020: Main report*. Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/ca9825en

Frontiers in Plant Science. (2026). *Accurate tree disc volume estimation using TLS: Validation and improvement via point cloud repair*. *Frontiers in Plant Science, 16*. https://doi.org/10.3389/fpls.2025.1654386

Global Carbon Project. (2023). *Global carbon budget 2023*. *Earth System Science Data, 15*(12), 5301–5369. https://doi.org/10.5194/essd-15-5301-2023

Forest Survey of India. (2023). *India state of forest report 2023*. Ministry of Environment, Forest and Climate Change, Government of India.

Remote Sensing. (2024). *Mobile devices in forest mensuration: A review of technologies and methods in single tree measurements*. *Remote Sensing, 16*(19), Article 3570. https://doi.org/10.3390/rs16193570

Westfall, J. A., Coulston, J. W., Walters, B. F., Russell, M. B., Nelson, M. D., Healey, S. P., & other contributors. (2024). *A national-scale tree volume, biomass, and carbon modeling system for the United States* (General Technical Report WO-104). USDA Forest Service. https://doi.org/10.2737/WO-GTR-104

Volume: 06 Issue No: 09

CANNABINOIDS: A NOVEL FUTURE THERAPEUTIC AGENT

Article ID: AG-V06-I09-95

Proloy Sankar Dev Roy

Assistant Professor-cum- Junior Scientist, Department of Biochemistry

Mewar University, Rajasthan, India

Abstract

Cannabinoids, are a biochemically diverse group of compounds under the terpenophenolic group of biomolecules produced by the plant Cannabis (*Cannabis sativa* L.). The plant is mostly used for its intoxicating and recreational properties. But with the advancement in the fields of natural products chemistry, pharmacology and medicinal chemistry research sculpted the blueprint of its therapeutic potential. Its interaction with the endocannabinoid system shows its pharmacological importance that can be used for medicinal purposes. A wide myriad of characterized bioactive comes under the umbrella of cannabinoids *viz.* △9-tetrahydrocannabinol (△9-THC), cannabidiol (CBD), cannabiochromene (CBC), cannabigerol (CBG) and cannabinol (CBN). Various literature suggests the use of cannabinoids most prominently the CBD as an important target having therapeutic potential. The phyto-cannabinoid CBD exhibits analgesic, anti-inflammatory and anticonvulsant potential as documented in wet lab pre-clinical trials. Outside the range of these therapeutic effects, it also has a prominent place being a strong anti-bacterial agent and the antagonist mechanism is bestowed by modulating the membrane vesicle release mechanism, membrane disruption and disruption of cell-envelope mechanisms. Its counterpart CBG also has medicinal properties which ranges from mitigating the ill effects of chemotherapy, neuroprotection and in treatment of epilepsy. But cannabinoids face challenges as most of the experimental data are in lab conditions lacking clinical support. So, the targeted future perspectives can be focussed on standardization of the formulations, optimization of the pharmacokinetics, toxicity and dosage assessment, contraindications with other drugs and

alignment with regulatory frame work. This technical article summarizes the vast therapeutic potential of the broad class of compounds, the cannabinoids.

Key words: Cannabis sativa, cannabinoids, cannabidiol, medicinal properties

1. Introduction

Nature has provided us with a wide booty of medicinal plants that have potent medicinal properties. Since time immemorial these plants have been used as folklore medicines for curing various ailments. With the development in the field of natural products chemistry and ethnobotanical pharmacology various untapped plants used for recreational purposes have been identified boasting of showing promising medicinal properties also owing to their potent pharmaceutically potent active ingredients. Active research in the field of pharmaceutical science, natural products chemistry and pharmaceutical kinetics have identified many pharmaceutically important active ingredients that can alleviate various ailments. Among the wide consortium of medicinal folklore plants Cannabis, *Cannabis sativa* holds a prominent position owing to be a rich source of pharmacologically potent compounds that have been identified in recent times with the development of analytical techniques and pharmacological research.

The major class of compound present in cannabis is the cannabinoids comprising of a wide array of compounds designated as the mother compound as phyto cannabinoids followed by endogenous and most recently the synthetic cannabinoids. Since time immemorial the main purpose of cannabis use was to increase the Gamma butyric acid (GABA) used for recreational and intoxicating purpose owing to the compound, Δ9-tetrahydrocannabinol (△9-THC). Besides these compounds cannabinoids also comprises of other potent compounds *viz.* cannabidiol (CBD), cannabinol (CBN), cannabigerol (CBG) and cannabichromene (CBC) (Murray et al., 2024). All these compounds play an important role in therapeutics but CBD is the most studied compound owing to its analgesic, anti-microbial, anti-inflammatory to name a few potentials. Various signalling pathways and receptors are responsible to incite the therapeutic potential of these compounds. The most prominent receptor being CB1 and CB2 receptors which holds a noble position for the interaction with the CBD to claim the therapeutic potential of cannabinoids. A transient shift from recreational purpose to standardized drugs has been documented by various authors in the recent literatures (Shen et al., 2025).

2. Pharmacology of Cannabinoids

As mentioned in the introductory part the action of the various bioactive compounds under the class cannabinoids are responsible for eliciting various receptors *viz.* CB1 & CB2 along with various signalling pathways. Among the active ingredients (AIs), some play an agonist role for recreational purposes by activating various neurotransmitter cascades, most prominently the △9-THC which affects various psychological and motor functions. It's effect on the CB2 receptor modulates the immune system and plays an important role inflammatory signalling pathway. In contrast to the △9-THC, its CBD counterpart has an important pharmacologically viable profile opening avenues for drug development targeting specific molecular sites literatures (Shen et al., 2025).

Being a biosynthetic precursor to a wide array of phyto-cannabinoids, CBD has little agonist effect to the neurotransmitter receptors *viz.* CB1and CB2 and poses as an active AI for drug development owing to its anti-analgesic and anti-inflammatory properties. The other players *viz.* CBC and CBN also exhibit medicinal properties that can be exploited and standardized for the development of new drugs.

3. Medicinal Properties of Cannabinoids

From ancient period ethnobotanical literatures have sited the use of Cannabis for recreational purposes owing to its intoxicating effects by modulating the neurotransmitter cocktail (Blaskovich et al.2021). But with developments in the field of natural products chemistry and pharmaceutical sciences, a transient shift has been witnessed of its use in drug development owing to its inherent pharmacologically important bio actives posing various medicinal properties *viz.* anti-analgesic, anti-inflammatory, anti-bacterial activity to cite a few. Various recent literatures support the use of this intoxicating plant for the development of drugs for alleviating various diseases (Murray et al., 2024).

3.1 Anti-microbial Properties and its Mechanism

Phyto-cannabinoids most prominently CBD play an important role as potent anti-microbial agents as they can modulate the membrane-vesicle architecture in microbes. With a rapid rise in the problem of antibiotic resistance exhibited by many microflora, scientists are keen towards new alternatives which can mitigate the process. Various processes have been identified for its anti-microbial activity like synergetic effect with antimicrobial agents, membrane disruption, immune-modulation etc. Major bio actives like CBD along with CBC

have shown promising antagonistic effects on various bacterial strains including both Gram + and Gram-. These phyto-cannabinoids have shown anti-microbial activity against various strains like *Staphylococcus aureus* (*S.aureus*) and *Escherichia coli* (*E.coli*) strains by disrupting the membrane-release mechanisms (Kosgodage et al.,2019).

The bio actives of cannabis also show anti-fungal properties but few literatures have been documented as the research is in budding stage and requires extensive invitro studies. Some of the AIs have shown inhibitory fungal action against some strains but needs to be standardized to be used for pharmacological value. It opens the path for further avenues to evaluate the pharmacokinetics and stability to be used as potent drugs cannabinoids (Antimicrobial Potential of Cannabinoids, 2025) .

The mechanism of anti-microbial action of the phyto-cannabinoids principally depends on the disruption of the microbial membrane (extracellular) vesicles resulting in the disruption of the intracellular communication and altering the host-pathogen interaction. Essential cellular processes of the microbe are altered owing to the lipophilic nature of the cannabinoids AIs altering the normal ion gradients mechanisms (Fang et al., 2024). The most important pharmacologically important player CBD, has been documented to alter/disturb the various important protein profiles of the vesicles thus impairing vesicle release in *E.coli.* These molecular mechanisms in a summarized way impart the anti-microbial properties to cannabinoids (Antimicrobial Potential of Cannabinoids, 2025).

3.2 Anti-cancer and Neuroprotective Properties

The broad class of cannabinoids as shown by research plays an important role in cancer biology as it can potentially induce apoptosis by reducing the oxidative stress and inciting the immune cascade. In future they can be used in combination with chemotherapy drugs but extensive research, clinical trials and standardization are required as these findings are in experimental setup. Moreover, cannabinoids also play an important role as therapeutics for neurological disorders (Chou et al., 2024). The main receptors of cannabinoids *viz.* CB1 and CB2 along with allosteric modulation play an important role in the neuroprotective nature of cannabinoids. Their interaction plays a vital role as they influence the cannabinoid signalling pathways thrusting the process of microglial activation and exciting the neuronal system (Jang et al., 2024).

Coupled with these therapeutic properties the broad class of cannabinoid compounds have several other clinically viable implications. CBD has been established to play a pivotal role in curing treatment resistant epilepsy by alleviating the symptoms of childhood onset epilepsy. Moreover, THC plays a role as a combinatory therapy along with chemotherapy to alleviate the side effects of chemotherapy like nausea etc. Another therapeutic example of cannabinoids is its effect in modulating the nociceptive signalling pathway responsible for its analgesic activity. Interaction of THC with the CB2 receptor (agonistic effect) also shows promising responses in pivoting the immune signalling cascade. Research have also showed the effects of CBD in alleviating insomnia, anxiety and enhanced cognitive responses (Shen et al., 2025). These documented effects show a projected role of cannabinoids in therapeutics but extensive clinical trials coupled with standardization is the need of the hour to declare cannabinoids as potent prescribed drugs to nullify any adverse contraindications and side-effects (Cassidas et al., 2024).

4. Challenges & Future Perspectives

The therapeutic potential of cannabinoids as cited by various literatures are accompanied by various cons and challenges. All results showing the therapeutic potential of cannabinoids as future drugs have been performed in vitro showing promising results but the formulations have not been yet standardized to suffice its true therapeutic usefulness as drugs. The medicinal efficacy of cannabinoids shows in situ potency in wet lab in various concentrations lacking ex situ data posing a threat to its efficacy at the actual local site of infection (Jang et al., 2024). Moreover, attention should be taken care of host toxicity and sign of any adverse side effects. Lastly, is the concept of formulation as the type of the formulation, its nature and solubility may play an important role in the delivery of the AIs. Attention should be also given to the regulatory framework as it varies from countries before its nomenclature as a standard prescribed drug (Fang et al., 2024) .

These challenges call for stringent research employing multi-disciplinary approach synergistically encompassing various branches of science *viz.* pharmacology, natural products chemistry, microbiology etc. With the advent of nanotechnology, it can be synchronized with the drug development process by inclusion of nano carriers like nano emulsions, liposomes etc. to promote targeted delivery and prevent degradation. Inclusion of multi-omics study can help in understanding the mode of action and mechanism of resistance. Lastly, for successful transition to clinical use, stringent research on pharmacodynamics, studies on dose ranges, drug

contraindications and standardization are the need of the hour to validate cannabinoids as future drugs to cure complex diseases.

Conclusion

Cannabinoids comprising of various phyto cannabinoids pose to be a suitable target for future therapeutic uses owing to their pharmacologically important compounds. Various bioactive compounds under the umbrella class cannabinoids particularly the CBD and CBG pose to exhibit therapeutic potential owing to diverse medicinal properties being anti-microbial, analgesic, anti-cancer and neuroprotective properties. Various literature has documented the role of these compounds as anti- bacterial agents because of various mechanism of action spanning form altering the membrane-vesicle alteration, membrane disruption, and modulating key cellular processes. Moreover, they also show synergistic effects with conventional antibiotics and nullifying the problem of drug resistance. In spite of being a key therapeutic agent the future is bleak because most of the studies are pre-clinical and to circumvent these challenges rigorous clinical trials, standardized formulations and dosage study is important to project it as future prescribed drug aligning with stringent regulatory framework.

References

Antimicrobial Potential of Cannabinoids: A Scoping Review of the Past 5 Years. (2025). *Microorganisms*, **13**(2), 325. https://doi.org/10.3390/microorganisms13020325

Blaskovich, M. A. T., et al. (2021). The antimicrobial potential of cannabidiol. *Communications Biology*, **4**, 7.

Cassidas, G., de Yarza-Sancho, M., & López, V. (2024). Cannabidiol (CBD): A systematic review of clinical and preclinical evidence in the treatment of pain. *Pharmaceuticals*, **17**(11), 1438. https://doi.org/10.3390/ph17111438

Chou, R., Ahmed, A. Y., Dana, T., Morasco, B. J., Bougatsos, C., Fu, R., Williams, L., & Ivlev, I. (2024). Living systematic review on cannabis and other plant-based treatments for chronic pain: 2024 update. *Agency for Healthcare Research and Quality*.

Fang, S., Kang, W.-T., Li, H., Cai, Q., Liang, W., Zeng, M., Yu, Q., Zhong, R., Tao, Y., Liu, S., & Lin, S. (2024). Development of cannabidiol derivatives as potent broad-spectrum antibacterial agents with membrane-disruptive mechanism. *European Journal of Medicinal Chemistry*, **266**, 116149. https://doi.org/10.1016/j.ejmech.2024.116149

Jang, J.-H., Jeong, J.-H., & Jeong, S.-H. (2024). Quantitative summary on the human pharmacokinetic properties of cannabidiol to accelerate scientific clinical application of cannabis. *Naunyn-Schmiedeberg's Archives of Pharmacology*, **397**(11), 8285–8309. https://doi.org/10.1007/s00210-024-03185-6

Kosgodage, U. S., Matewele, P., Awamaria, B., Kraev, I., Warde, P., Mastroianni, G., Nunn, A. V., Guy, G. W., Bell, J. D., Inal, J. M., & Lange, S. (2019). Cannabidiol is a novel modulator of bacterial membrane vesicles. *Frontiers in Cellular and Infection Microbiology*, **9,** 324. https://doi.org/10.3389/fcimb.2019.00324

Murray, C. H., et al. (2024). The development of cannabinoids as therapeutic agents in the United States. *Pharmacological Reviews*. https://doi.org/10.1124/pharmrev.123.001121

Shen, S.-Y., Wu, C., Yang, Z.-Q., Wang, K.-X., Shao, Z.-H., & Yan, W. (2025). Advances in cannabinoid receptors pharmacology: From receptor structural insights to ligand discovery. *Acta Pharmacologica Sinica*, **46**, 1495–1510. https://doi.org/10.1038/s41401-024-01472-9

Volume: 06 Issue No: 09

AI AND EMERGING TECHNOLOGIES IN FRUIT QUALITY ASSESSMENT AND FOOD PROCESSING

Article ID: AG-V06-I09-96

Manuj Awasthi[1*] and Deeksha Semwal[2]

[1]Department of Fruit Science, C.S. Azad University of Agriculture and Technology, Kanpur-208002, U.P. India

[2]Department of Food Science & Technology, G. B. Pant University of Agriculture &Technology, Pantnagar, Udham Singh Nagar, Uttarakhand 263145, India

*Corresponding Author : Manuj Awasthi

Introduction

Fruits are an important component of a healthy diet and contribute significantly to nutritional security, farmers' income and the food-processing industry. India is one of the leading producers of fruits in the world, with a wide diversity of tropical, subtropical and temperate fruit crops. However, a considerable quantity of fruits is lost between harvesting and final consumption because of improper harvesting, handling, transportation, storage and processing. Variations in fruit maturity, size, colour, firmness, nutritional composition and susceptibility to diseases further complicate quality management.

Traditionally, fruit quality assessment has relied heavily on visual inspection and laboratory-based methods. Although these methods are useful, they can be time-consuming, subjective and destructive in many cases. Recent developments in Artificial Intelligence (AI), machine learning, computer vision, hyperspectral imaging, Internet of Things (IoT), robotics and non-destructive sensing technologies are transforming the way fruit quality is evaluated and processed.

The integration of these technologies can facilitate rapid, objective and non-destructive assessment of fruit quality while improving processing efficiency, reducing waste and enhancing food safety. The future of fruit production and processing is therefore moving towards intelligent, automated and data-driven systems.

AI in Fruit Quality Assessment

Artificial Intelligence refers to computer-based systems capable of performing tasks that normally require human intelligence, such as recognition, classification, prediction and decision-making. In horticulture, AI is increasingly being used to analyse images and sensor-generated data for assessing fruit quality.

1. Computer Vision for Fruit Grading

Computer vision is one of the most promising applications of AI in post-harvest horticulture. Cameras can capture images of fruits moving on conveyor systems, while AI algorithms analyse characteristics such as colour, size, shape, surface defects and external damage.

Machine learning and deep learning models can classify fruits according to different quality grades. For example, healthy and marketable fruits can be separated from fruits showing bruises, cracks, fungal infection, sunburn or other defects.

Unlike manual grading, automated systems can operate continuously at high speed and provide more consistent classification. Such systems have considerable potential for commercial packhouses and food-processing industries.

2. Detection of Maturity and Ripeness

Determining the correct maturity stage is essential for harvesting, storage and marketing. Fruits harvested too early may have poor flavour and nutritional quality, whereas overripe fruits generally have shorter shelf life.

AI-based image analysis can identify subtle changes in fruit colour and surface characteristics associated with ripening. By combining image data with environmental and physiological information, machine learning models can also predict the maturity stage of fruits. Such technologies can support farmers and packhouses in determining appropriate harvesting and marketing times.

3. Detection of Diseases and Defects

Post-harvest diseases are a major cause of fruit losses. Conventional disease identification generally depends on visual examination by trained personnel. AI-based systems can assist in detecting disease symptoms at an early stage.

Deep learning models, particularly convolutional neural networks (CNNs), can analyse images and identify characteristic patterns associated with fungal infections and other defects.

Early detection allows affected fruits to be removed before they contaminate healthy produce during storage and transportation.

However, AI systems should be properly trained and validated under real commercial conditions because lighting, fruit variety, background and disease stage can influence image-based diagnosis.

Emerging Non-Destructive Technologies

AI becomes even more powerful when combined with advanced sensing technologies. Several non-destructive techniques are being developed for evaluating internal as well as external fruit quality.

Hyperspectral Imaging

Hyperspectral imaging combines conventional imaging with spectroscopy. It provides information across a broad range of wavelengths and can reveal chemical and structural characteristics that may not be visible to the human eye.

Hyperspectral systems have potential for assessing internal defects, maturity, moisture, sugar-related characteristics and other quality parameters. When hyperspectral data are analysed using machine learning algorithms, complex relationships between spectral information and fruit quality can be identified.

This technology is particularly promising for high-value fruits where rapid and non-destructive quality assessment can provide significant economic benefits.

Near-Infrared Spectroscopy

Near-infrared (NIR) spectroscopy is another important technology for non-destructive quality evaluation. It can be used to estimate internal characteristics such as soluble solids, moisture and other quality-related parameters.

Unlike conventional laboratory analysis, NIR-based approaches can potentially evaluate fruits without destroying the sample. Portable NIR instruments may also enable quality assessment closer to the farm or during transportation and marketing.

Internet of Things and Smart Monitoring

The Internet of Things (IoT) involves connecting sensors and devices so that data can be collected and communicated in real time. In fruit supply chains, IoT sensors can monitor temperature, relative humidity, ethylene concentration and other environmental conditions.

Smart monitoring systems can help identify unsuitable storage conditions before significant deterioration occurs. Data collected from cold-storage units and transportation vehicles can be analysed using AI to predict shelf-life and quality changes.

For example, if temperature and humidity conditions deviate from recommended levels, an intelligent system could generate an alert. This can help reduce storage losses and maintain fruit quality throughout the supply chain.

Robotics and Automation in Fruit Processing

- The combination of AI and robotics is creating new possibilities for automated fruit handling and processing. Robotic systems can perform tasks such as sorting, grading, picking, handling and packaging.
- AI-enabled robotic systems can identify fruits, determine their position and estimate their quality before performing a specific operation. Automation can reduce dependence on repetitive manual labour and improve processing efficiency.
- In processing plants, automated sorting systems can separate fruits according to size, colour and quality. Robotic handling can also minimise unnecessary mechanical damage when appropriately designed.

AI in Food Processing

The application of AI is not limited to fresh fruit quality assessment. It is increasingly relevant throughout the food-processing chain.

Process Optimization

Fruit processing involves several operations such as washing, peeling, cutting, pulping, drying, concentration, pasteurization and packaging. Each operation can influence the nutritional, sensory and microbiological quality of the final product.

AI models can analyse processing parameters and help identify suitable combinations of temperature, time, moisture and other variables. This can support consistent product quality while reducing energy and raw-material losses.

Prediction of Shelf Life

- Shelf-life prediction is an important challenge for fruit and fruit-based products. Traditionally, shelf-life studies require considerable time and controlled experiments.
- Machine learning models can potentially combine information related to storage temperature, humidity, packaging, product composition and microbial changes to predict

quality deterioration. Such predictive systems could assist processors in inventory management and reduce unnecessary product disposal.

Intelligent Packaging

- Packaging plays an important role in protecting fruits and processed products from physical damage, moisture loss, oxidation and microbial contamination.
- Emerging technologies include smart packaging systems capable of providing information about product condition. Sensors or indicators may respond to changes in temperature, gases or other quality-related parameters.
- When integrated with digital technologies, intelligent packaging could provide real-time information throughout the supply chain and support better decisions regarding storage and distribution.

Reducing Food Waste through Technology

- One of the most important advantages of AI and emerging technologies is their potential to reduce food loss and waste.
- Accurate grading can prevent acceptable fruits from being rejected because of minor or subjective quality differences. Early disease detection can prevent the spread of infection during storage. Predictive systems can help processors and retailers manage inventories according to expected shelf life.
- Furthermore, fruits that do not meet fresh-market standards because of size or appearance can be diverted towards processing. They can be converted into pulp, juice, puree, dried products, jams, beverages, functional ingredients and other value-added products.
- Thus, intelligent quality assessment can support a more efficient and sustainable “farm-to-fork” food system.

Opportunities for Farmers and Food Entrepreneurs

- The adoption of AI and emerging technologies is not limited to large industries. With the development of low-cost sensors, mobile applications and cloud-based platforms, digital technologies are becoming increasingly accessible.
- Farmers can potentially use smartphone-based applications for preliminary assessment of fruit maturity and quality. Farmer Producer Organizations (FPOs), cooperatives and small

processing enterprises can adopt digital grading and traceability systems to improve market access and product consistency.

- For rural entrepreneurs, fruit processing combined with digital quality management can create opportunities for value addition and employment. Technologies that convert processing residues such as peels, seeds and pomace into useful ingredients can further contribute to a circular economy.

Challenges in Adoption

Despite their potential, several challenges need to be addressed before these technologies can be widely adopted.

I. AI models require large and high-quality datasets representing different fruit cultivars, growing conditions, maturity stages and environmental conditions. A model developed under laboratory conditions may not always perform equally well in commercial orchards or packhouses.

II. The initial investment required for advanced imaging systems, sensors, robotics and processing equipment can be substantial. This may limit adoption by small farmers and small-scale processors.

III. Skilled personnel are required to operate, maintain and interpret advanced technologies. Training and capacity building will therefore be essential.

Data standardization, interoperability, cybersecurity and reliable internet connectivity are additional considerations for large-scale digital agriculture systems.

Future Prospects

The future of fruit quality assessment and food processing is likely to involve greater integration of AI with multiple sensing technologies. Instead of relying on a single parameter, future systems may combine images, spectral information, temperature, humidity, biochemical data and supply-chain information to provide a comprehensive quality assessment.

Portable sensors, smartphone-based applications, edge computing and cloud platforms could make advanced quality assessment more accessible. Digital twins and predictive models may eventually allow processors to simulate different processing and storage conditions before applying them to actual production systems.

Another important direction is the development of explainable AI. In food and agriculture, users need to understand why a system has classified a fruit as defective or predicted

a particular shelf life. Transparent and interpretable AI systems will therefore be important for practical adoption.

Conclusion

Artificial Intelligence and emerging technologies are opening new avenues for improving fruit quality assessment, post-harvest management and food processing. Computer vision can automate grading and defect detection, while hyperspectral imaging and spectroscopy can provide non-destructive information about internal quality. IoT systems can enable real-time monitoring of storage and transportation conditions, and robotics can improve efficiency in sorting and processing.

The greatest potential lies in integrating these technologies into a connected farm-to-fork system. Such integration can help reduce post-harvest losses, improve food quality and safety, increase processing efficiency and create opportunities for value addition.

For a fruit-producing country such as India, the adoption of appropriate and affordable digital technologies can contribute to sustainable horticulture, better farmer returns and a more efficient food-processing sector. The future of fruit quality management will therefore increasingly depend on the convergence of horticulture, food technology, artificial intelligence and data-driven decision-making.

Volume: 06 Issue No: 09

DROUGHT STRESS: ITS CAUSES AND MITIGATION PRACTICES IN PLANTS

Article ID: AG-VO6-I09-97

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture,

Jobner (Rajasthan)-303329, India

Introduction

Drought stress is a condition in which a plant experiences insufficient water availability for normal growth, development, and physiological functions. It occurs when the amount of water lost by the plant through transpiration is greater than the amount of water absorbed by the roots. Drought stress is one of the major **abiotic stresses** affecting agricultural crops, particularly in arid and semi-arid regions such as Rajasthan. It can reduce germination, photosynthesis, nutrient uptake, growth, yield, and fruit quality.

Causes of Drought Stress: Major causes include:

i. Low and irregular rainfall – inadequate precipitation reduces soil-water availability.

1. **High temperature** – increases evaporation and transpiration.
2. **Low soil moisture** – insufficient water remains available in the root zone.
3. **High evaporative demand** – dry air and strong winds increase water loss.
4. **Poor soil structure** – compact or sandy soils may have poor water-holding capacity.
5. **Excessive irrigation or poor irrigation management** – can lead to inefficient use of available water.
6. **Deforestation and land degradation** – reduce soil moisture conservation.
7. **High plant population** – excessive competition among plants for limited water.
8. **Salinity** – high soil salinity makes it physiologically difficult for roots to absorb water.
9. **Climate change** – changing rainfall patterns and increasing temperature can intensify drought conditions.

Types of Drought Stress

A. **Meteorological drought**: Occurs when rainfall is significantly below the normal level for a particular period.

B. **Agricultural drought**: Occurs when soil moisture becomes insufficient to meet the water requirements of crops, resulting in reduced growth and yield.

C. **Hydrological drought**: Occurs when prolonged water shortage reduces the water level of rivers, reservoirs, lakes, and groundwater.

D. **Physiological drought**: Occurs when water is present in the soil but plants cannot absorb sufficient water because of high salinity, low temperature, or other unfavorable conditions.

E. **Soil or edaphic drought**: Occurs when the soil contains insufficient available water in the plant-root zone.

F. Temporary and permanent drought

- **Temporary drought:** short periods of water shortage from which plants may recover.
- **Permanent/severe drought:** prolonged water deficiency causing serious physiological damage or plant death.

Effects of Drought Stress on Plants

A. Effects on seed germination

- Reduces water absorption by seeds Delays germination.
- Reduces germination percentage Produces weak seedlings.

B. Effects on root growth: Plants often respond to moderate drought by increasing root growth relative to shoot growth.

However, severe drought can:

- Inhibit root elongation, Reduce root activity,
- Damage root tissues, Reduce nutrient and water uptake.

C. Effects on shoot growth: Drought causes:

- Reduced cell expansion Reduced leaf area
- Shorter shoots Reduced biomass
- Premature leaf senescence.

D. Effects on stomata: Water deficiency causes **stomatal closure** to reduce transpiration. However, stomatal closure also restricts the entry of CO_2 into leaves.

E. Effects on photosynthesis: Drought stress reduces photosynthesis through:

- Stomatal closure Reduced CO_2 availability
- Damage to chloroplasts Reduction in photosynthetic pigments
- Oxidative damage to photosynthetic machinery.

F. **Effects on respiration**: Moderate drought may alter respiration, while severe drought can disturb cellular metabolism and energy balance.

G. **Effects on nutrient uptake**: Reduced soil moisture decreases nutrient mobility and root absorption, resulting in deficiencies of nutrients such as N, P, K and micronutrients.

H. Effects on flowering and fruiting: Drought can cause:

- Poor flowering Flower abortion Reduced fruit set,
- Increased fruit drop Smaller fruits Reduced yield.

I. Effects on yield: Severe drought may substantially reduce:

- grain yield fruit yield vegetable production
- biomass seed quality.

Mechanism of Drought Stress in Plants : The plant response to drought occurs through several interconnected mechanisms.

1. Reduction in plant water potential: When soil water decreases, the water potential of the soil becomes more negative. Plants experience difficulty in absorbing water.

2. Stomatal closure: Drought stimulates production and accumulation of abscisic acid (ABA). ABA promotes stomatal closure, reducing water loss through transpiration.

Drought → ABA increase → stomatal closure → reduced water loss

However, stomatal closure also reduces CO_2 uptake and therefore photosynthesis.

3. Osmotic adjustment: Plants accumulate compatible solutes such as:

- Proline Soluble sugars Amino acids
- Glycine betaine Organic acids Inorganic ions

These compounds help maintain cell turgor and water absorption.

4. Antioxidant defense: Drought increases the formation of **reactive oxygen species (ROS)** such as superoxide radicals and hydrogen peroxide.

Plants protect themselves using antioxidant systems including:

- Superoxide dismutase (SOD) Catalase (CAT) Ascorbate peroxidase (APX)
- Glutathione reductase (GR) Ascorbate Glutathione

5. Root adaptation: Plants may develop:

- Deeper roots Greater root-to-shoot ratio,
- Increased root branching Improved root hydraulic conductivity.

These adaptations help plants obtain water from deeper soil layers.

6. Gene and protein regulation: Drought activates stress-responsive genes and proteins involved in:

- Water transport Osmotic adjustment Antioxidant defense
- Stress signaling Cellular protection

7. Membrane and cellular protection: Drought-induced oxidative stress can damage cell membranes, proteins, DNA, and chloroplasts. Plants therefore increase protective mechanisms to maintain cellular integrity.

How to Mitigate Drought Stress: Drought stress can be reduced through water management, agronomic practices, breeding, and physiological approaches.

A. Efficient irrigation

- Use **drip irrigation** where suitable.
- Apply irrigation according to crop growth stage and soil moisture.
- Avoid unnecessary irrigation losses.
- Use efficient irrigation scheduling.

B. Mulching

Organic or plastic mulch can:

- Reduce evaporation,
- Conserve soil moisture,
- Moderate soil temperature,
- Suppress weeds.

C. Soil moisture conservation

Useful practices include:

- Contour farming Bunding Conservation tillage
- Minimum tillage rainwater harvesting Addition of organic matter.

D. Selection of drought-tolerant varieties: Cultivars with:

- Deep root systems Efficient water use Good osmotic adjustment
- Strong antioxidant systems Early maturity can perform better under drought.

E. Seed priming: Seed priming can improve:

- Germination Seedling establishment Root development Drought tolerance

Hydropriming, osmopriming and appropriate chemical/biological priming methods may be used.

F. Balanced nutrition: Adequate nutrition, particularly appropriate management of potassium, phosphorus and micronutrients, can support water relations, root development and stress tolerance.

G. Plant growth regulators and bio stimulants: Depending on the crop and application method, substances such as ABA, salicylic acid, brassinosteroids, cytokinins, seaweed extracts and other biostimulants may improve drought-response mechanisms. Their effectiveness is strongly dependent on dose, crop, growth stage and environmental conditions.

H. Weed management: Weeds compete with crops for limited water. Timely weed control can therefore conserve soil moisture.

I. Adjusting sowing time: Sowing should be timed to make maximum use of available rainfall and avoid critical crop stages coinciding with severe drought.

J. Agroforestry and shelterbelts: Trees and windbreaks can reduce wind speed and evaporation and improve the microclimate, when appropriately designed for the cropping system.

Summary: Drought stress is a major abiotic stress caused by inadequate water availability relative to plant demand. It is particularly important in arid and semi-arid agricultural regions. Drought affects plants at almost every level, from seed germination to flowering, fruit development and final yield. The major physiological responses include stomatal closure, reduced photosynthesis, osmotic adjustment, increased root development and activation of antioxidant defenses. Plants accumulate compounds such as proline and soluble sugars and activate enzymes that protect cells from oxidative damage.

Drought stress can be mitigated through efficient irrigation, mulching, rainwater harvesting, soil-moisture conservation, drought-tolerant varieties, seed priming, balanced nutrition, weed management and suitable agronomic practices. An integrated approach combining these methods is the most effective way to maintain crop productivity under water-limited conditions.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

HIGH TEMPERATURE STRESS: ITS CAUSES AND PROTECTION MEASURES IN PLANTS

Article ID: AG-V06-I09-98

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture,

Jobner (Rajasthan)-303329, India

Introduction

High temperature stress (heat stress) is a type of abiotic stress that occurs when plants are exposed to temperatures above their optimum range for a sufficient period to disturb normal physiological, biochemical, and metabolic processes. The critical temperature varies with plant species, cultivar, and developmental stage, duration of exposure, humidity, water availability, and acclimation history. Heat stress is particularly damaging during flowering, pollination, and early seed/fruit development.

Causes of High Temperature Stress

Major causes include:

1. **High atmospheric temperature** due to heat waves and hot weather.
2. **Global climate change** and increasing frequency of heat waves.
3. **Low soil moisture**, which reduces evaporative cooling.
4. **High solar radiation** and strong sunlight.
5. **Hot dry winds (loo)**, especially in arid and semi-arid regions.
6. **Poor irrigation management** or inadequate water supply.
7. **High plant population density**, which can increase competition for water.
8. **Heat accumulation in protected structures**, such as greenhouses and polyhouses.
9. **Dark-coloured or poorly ventilated soils/structures** that absorb excessive heat.
10. **Urban heat-island effects** in some production areas.

Types of High Temperature Stress

A. Based on duration

1. Short-term heat stress

- Exposure to high temperature for a few hours or days.
- May cause temporary damage if the plant can recover.

2. Long-term or chronic heat stress

- Exposure to moderately high temperature for several days or weeks.
- Causes prolonged reduction in growth and productivity.

B. Based on intensity

1. Moderate heat stress

- Temperature is above optimum but below the lethal level.
- Plants may acclimate through physiological and biochemical adjustments.

2. Severe heat stress

- Temperature is sufficiently high to cause rapid cellular injury, protein denaturation, membrane damage and sometimes plant death.

C. Based on occurrence

1. Day-time heat stress – occurs mainly because of high daytime temperature and solar radiation.

2. Night-time heat stress – occurs when night temperature remains unusually high, reducing respiration recovery and affecting flowering and grain filling.

3. Combined heat and drought stress – particularly severe because reduced soil water limits transpiration and therefore the plant's ability to cool itself.

Effects of High Temperature Stress on Plants

A. Effects on germination and seedlings

- Reduced seed germination.
- Delayed or abnormal seedling emergence.
- Reduced root and shoot growth.
- Loss of seedling vigour.
- Increased seedling mortality.

B. Effects on vegetative growth

- Reduction in plant height.
- Premature leaf senescence.
- Reduced root growth.
- Reduced leaf area.
- Leaf rolling, wilting and scorching.
- Reduced biomass production.

C. Effects on photosynthesis: High temperature causes:

- Closure of stomata. Reduction in CO_2 uptake.
- Damage to chloroplast membranes Inhibition of photosystem II.
- Reduction in chlorophyll content Increased photo-oxidative damage.

Consequently, photosynthetic rate decreases.

D. Effects on respiration: Heat stress generally increases respiration initially, resulting in:

- Greater consumption of stored carbohydrates.
- Reduced availability of assimilates for growth.
- Increased production of reactive oxygen species (ROS).

Under prolonged severe stress, respiratory metabolism may become impaired.

E. Effects on flowering and pollination: This is one of the most sensitive stages.

High temperature can cause:

- Poor flower initiation Abnormal flower development.
- Reduced pollen viability Reduced pollen germination.
- Poor pollen-tube growth Anther sterility.
- Reduced fertilization Flower and fruit drop.

Therefore, heat stress during flowering can cause a large reduction in yield.

F. Effects on fruits and seeds

- Reduced fruit set Increased fruit drop.
- Sunburn and sunscald Poor fruit development.
- Reduced seed size Reduced grain filling.
- Poor seed quality Premature maturity.

G. Effects on biochemical processes: Heat stress can cause:

- Protein denaturation Enzyme inactivation.
- Membrane lipid peroxidation Increased ROS production.
- Reduction in antioxidant balance Changes in carbohydrate metabolism.
- Disturbance of hormonal balance

Mechanism of High Temperature Stress: The mechanism can be summarized as:

High temperature → increased membrane fluidity → protein/enzyme damage → ROS production → oxidative stress → photosynthetic and metabolic inhibition → cellular injury → reduced growth and yield

Important mechanisms

1. Membrane damage: High temperature increases membrane fluidity and disrupts membrane integrity. This affects:

- Ion transport Cellular compartmentation
- Photosynthesis Respiration

2. Protein denaturation: Excessive temperature can alter protein structure and enzyme activity. Plants therefore produce **heat-shock proteins (HSPs)** that help protect and refold damaged proteins.

3. Reactive oxygen species production: Heat stress increases ROS such as:

- Superoxide radicals (O_2^-) Hydrogen peroxide (H_2O_2) Hydroxyl radicals ($OH\cdot$)

Excessive ROS causes oxidative damage to lipids, proteins, DNA and membranes.

4. Photosynthetic inhibition: Heat damages the photosynthetic apparatus, particularly Photosystem II, while stomatal closure restricts CO_2 availability.

5. Antioxidant response: Plants activate antioxidant systems including:

- Superoxide dismutase (SOD) Catalase (CAT)
- Ascorbate peroxidase (APX) Glutathione reductase (GR)
- Peroxidases (POD)

These enzymes detoxify excessive ROS.

6. Osmotic adjustment: Heat-tolerant plants accumulate compatible solutes such as:

Proline Soluble sugars Glycine betaine Polyols

These help maintain cellular water balance and stabilize proteins and membranes.

7. Hormonal changes: Heat stress alters the balance of

- Abscisic acid (ABA) Ethylene Auxins
- Cytokinins Gibberellins Salicylic acid

These hormones regulate stomatal behaviour, growth, senescence and stress responses.

Alleviation of High Temperature Stress Effects in Plants

A. Water management

1. Provide timely irrigation.
2. Use drip or sprinkler irrigation where appropriate.
3. Avoid severe water deficit during flowering and fruit development.
4. Use mulching to conserve soil moisture.

5. Improve soil water-holding capacity by adding organic matter.

B. Mulching: Organic or suitable synthetic mulches:

- Reduce soil temperature Reduce evaporation.
- Maintain soil moisture Protect roots from excessive temperature.

C. Shade management

- Shade nets can reduce excessive radiation.
- Temporary shading can be useful during extreme heat waves.
- In protected cultivation, use appropriate shade and ventilation.

D. Antitranspirants: Suitable antitranspirants may reduce excessive water loss and help maintain plant water status. Their use should be based on crop, environmental conditions and recommended concentrations.

E. Foliar application of protective substances:

- Depending on the crop and local recommendations, heat tolerance may be improved using substances such as:
- Salicylic acid, Silicon, Potassium, Calcium, Ascorbic acid, Glycine betaine, Proline and Certain plant growth regulators, these treatments may improve antioxidant activity, membrane stability and osmotic adjustment.

F. Nutrient management: Balanced nutrition is important, particularly adequate:

- Potassium, Calcium, Silicon, where beneficial, Nitrogen in appropriate amounts

Excess nitrogen should be avoided, because lush vegetative growth may increase water demand and susceptibility under heat and drought.

G. Crop management

- Adjust sowing/planting dates to avoid the hottest period during sensitive developmental stages.
- Maintain optimum plant population.
- Use appropriate irrigation scheduling.
- Maintain weed control to reduce competition for water.
- Use windbreaks where appropriate in hot, dry environments.

H. Protected cultivation management: In greenhouses/polyhouses:

- Improve ventilation
- Use shade nets.

- Use evaporative cooling where appropriate.
- Avoid excessive humidity combined with poor ventilation.
- Monitor temperature regularly.

I. Breeding and selection: Development and cultivation of **heat-tolerant cultivars** is one of the most effective long-term approaches.

Selection may be based on:

- High pollen viability
- High membrane stability
- Deep and extensive root systems
- High yield under heat conditions
- Stable photosynthesis
- Efficient antioxidant activity
- Better water-use efficiency

Classification of Plants According to High Temperature Tolerance: The exact temperature limits vary considerably among species and developmental stages, so plants are better classified **comparatively** rather than by one universal temperature threshold.

A. Highly heat-tolerant crops

Examples include: Pearl millet, Sorghum, Sesame, Cowpea, Pigeonpea, Cluster bean (guar), Date palm

These crops generally perform comparatively well under hot and dry conditions, although extreme heat can still damage them.

B. Moderately heat-tolerant crops

Examples:

- **Cotton, Groundnut, Sunflower, Castor, Chickpea**
- **Pigeonpea** at appropriate developmental stages
- **Maize**, depending on genotype and growth stage

C. Relatively heat-sensitive crops

Examples:

- **Wheat**, especially during flowering and grain filling
- **Potato, Pea, Lettuce, Spinach,**
- **Tomato**, particularly during flowering
- **Common bean**
- Many temperate vegetable crops

Important point: A crop may be heat tolerant during one developmental stage but heat sensitive during another. For example, wheat may tolerate relatively high temperatures during some vegetative stages but is highly sensitive to heat during flowering and grain filling.

8. Heat-Tolerant vs Heat-Susceptible Plants

Characteristic	Heat-tolerant plants	Heat-susceptible plants
Membrane stability	High	Low
Photosynthesis under heat	Maintained better	Strongly reduced
Pollen viability	Relatively high	Strongly reduced
Antioxidant activity	Strong	Relatively weak
ROS damage	Lower	Higher
Heat-shock proteins	Effective induction	Less effective response
Water-use efficiency	Generally better	Often poorer
Recovery after heat	Faster	Slower
Yield under heat	Relatively stable	Strongly reduced

Conclusion

High temperature stress is an important abiotic stress that limits crop growth, productivity and quality. It affects germination, vegetative growth, photosynthesis, respiration, flowering, pollen viability, fertilization, fruit/seed development and final yield.The major mechanisms include membrane destabilization, protein denaturation, ROS accumulation, photosynthetic inhibition, oxidative stress, altered hormonal balance and disturbed water relations. Plants defend themselves through heat-shock proteins, antioxidant enzymes, osmolyte accumulation, improved water regulation, membrane stabilization and physiological acclimation. The most effective management approaches include timely irrigation, mulching, shading, proper nutrient management, suitable planting dates, improved ventilation, protective foliar treatments and cultivation of heat-tolerant cultivars. In the context of arid and semi-arid agriculture such as Rajasthan, combining heat-tolerant varieties with efficient irrigation, mulching and appropriate crop scheduling is particularly important for maintaining crop productivity under increasing heat stress

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

GAC: BEYOND THE RED ARIL: UNLOCKING THE WHOLE-FRUIT POTENTIAL OF AN UNDERUTILIZED TROPICAL FRUIT

Article ID: AG-V06-I09-99

[*1] Dr. M. Lakshmi Kamala, [2] Dr. N.V.S.Supriya and [3] Dr. P. Srinivasu

[1,2,3] Teaching Associate, Dr. Y.S.R. Horticultural University, Venkataramannagudem – 534101, Godavari, Andhra Pradesh, India

*Corresponding Author : Dr. M. Lakshmi Kamala

Abstract

Gac (*Momordica cochinchinensis* Spreng.) is an underutilized tropical fruit with considerable potential for value-added food products because of its carotenoid-rich aril and the presence of bioactive compounds in other fruit fractions. Although processing has traditionally focused on the aril, Gac fruit comprises distinct fractions, including peel, pulp, aril and seeds, each possessing different compositional and technological characteristics. The yellow pulp constitutes a substantial proportion of the fruit and, together with the peel, contains carotenoids and other phytochemicals that may be utilized for the development of powders, natural colourants, extracts and composite food products. The aril remains the principal fraction for high-value applications such as dried powder, oil, juice, puree and functional food formulations. Seeds also represent a potential resource, particularly for oil recovery, although their food applications require further investigation. This article discusses the potential of fraction-specific processing as an approach for improving raw-material utilization, reducing processing residues and diversifying Gac-based products. Greater integration of aril, pulp, peel and seed utilization could transform Gac processing from an aril-dominated system into a multi-product value chain, thereby improving resource efficiency and the commercial potential of this underutilized fruit crop.

Keywords: *Momordica cochinchinensis*, whole-fruit utilization, carotenoids, fraction-specific processing, Gac-based products

Introduction

Gac (*Momordica cochinchinensis* Spreng.) has attracted increasing attention because of its distinctive red aril and high concentration of carotenoids, particularly lycopene and β-carotene. The aril is the most widely recognized component of the fruit and has become the principal target for nutritional and food-processing research. However, concentrating almost exclusively on the aril does not represent the full potential of the fruit.

A mature Gac fruit consists of several anatomically distinct fractions—peel, pulp, aril and seeds. These fractions differ in their relative proportions and in the distribution of carotenoids, phenolic compounds, flavonoids, fatty acids and other constituents. The yellow pulp represents a substantial fraction of the fruit, whereas the aril is comparatively smaller but particularly valuable because of its carotenoid and fatty-acid content (Kha and Nguyen, 2022; Ariyarathna and Gamage, 2024).

The presence of potentially valuable constituents beyond the aril provides a basis for considering Gac as a whole-fruit processing resource. Rather than treating the remaining fractions as unavoidable residues, their composition and technological properties can be considered when developing fraction-specific products. Such an approach could improve raw-material utilization, reduce processing residues and create additional value streams from the same harvested fruit.



Ripe Gac fruit showing its characteristic spiny exterior and carotenoid-rich red aril.

Gac: A Fruit with Multiple Processing Resources

The conventional perception of Gac as primarily a carotenoid-rich aril-producing fruit does not fully reflect the diversity of resources contained within the fruit. The chemical

composition of Gac varies among its anatomical fractions, providing opportunities for different processing routes.

The aril is particularly important because of its high lycopene and β-carotene content and its established applications in food products. The pulp occurs in relatively large quantities and contains carotenoids and other bioactive constituents, making it important from a resource-utilization perspective. The peel has also been identified as a source of carotenoids and other phytochemicals, while the seeds represent another fraction with potential for further investigation, particularly in relation to oil utilization (Kubola and Siriamornpun, 2011; Kha and Nguyen, 2022; Ariyarathna and Gamage, 2024).

This compositional heterogeneity suggests that Gac need not be viewed as a single homogeneous raw material. Instead, individual fractions can be evaluated according to their composition, functionality and suitability for specific products.



Major anatomical fractions of Gac A) fruit: peel, B) pulp, C) aril and seed.

The Aril: Gac's Principal High-Value Fraction

The aril remains the principal target of Gac processing because of its intense red colour and high concentration of carotenoids, particularly lycopene and β-carotene. These characteristics give the aril both nutritional importance and technological value as a source of natural colour and functional ingredients.

Fresh Gac aril can be chilled or frozen to extend its usability, while drying provides a means of converting the highly perishable material into a more stable ingredient. Dried aril can subsequently be milled into powder for incorporation into food formulations. Oil extraction

represents another important processing pathway because the aril contains carotenoids together with fatty acids (Kha and Nguyen, 2022).

Several applications of Gac aril have been reported, including frozen aril, dried aril powder, Gac oil, juice and puree. Gac powder has also been incorporated into traditional and formulated food products such as Xoi Gac, pasteurized juice, milk beverages, yoghurt, pasta and sauces (Ariyarathna and Gamage, 2024).

The Yellow Pulp: An Underutilized Resource

Although the aril receives the greatest attention, the yellow pulp represents a substantial proportion of the fruit and is consequently important for overall raw-material efficiency. When processing is focused primarily on aril recovery, a considerable quantity of pulp may remain outside the principal value chain.

Gac pulp contains carotenoids and other bioactive compounds, and differences in the distribution of these constituents among fruit fractions indicate that the pulp should not be considered merely as a processing residue (Kubola and Siriamornpun, 2011; Ariyarathna and Gamage, 2024). Its relatively large quantity also makes pulp utilization particularly relevant for improving the proportion of harvested fruit converted into useful products.

Potential applications include pulp powders, purees and composite food formulations. Gac pulp has also been investigated as a drying aid in the manufacture of Gac fruit powder. Incorporation of pulp into the drying formulation provides an alternative to complete separation and disposal of the pulp before powder manufacture and may allow a greater proportion of the fruit to be retained in the final product (Kha and Nguyen, 2022).

Peel: From Processing Residue to Potential Resource

Fruit peel is commonly removed during processing and subsequently treated as waste. However, the increasing emphasis on sustainable food processing has encouraged greater interest in recovering useful compounds from secondary fruit fractions. Gac peel provides a relevant example because it contains carotenoids and other phytochemicals.

Gac peel has been identified as a source of carotenoids, including lutein, while other studies have demonstrated the distribution of phenolic and related bioactive constituents among Gac fruit fractions (Kubola and Siriamornpun, 2011; Ariyarathna and Gamage, 2024). These characteristics provide a basis for exploring peel as a raw material for dried powders, natural colour applications and bioactive-rich extracts.

However, the identification of bioactive compounds alone does not establish a commercial product. Suitable processing conditions, safety, stability, sensory characteristics and economic feasibility must be evaluated before peel-derived products can be widely adopted.

Seeds: An Opportunity for Further Exploration

Gac seeds constitute another major anatomical fraction separated during aril processing. Traditional processing may involve drying fruit material with the seeds followed by separation before further processing or oil production (Kha and Nguyen, 2022).

The presence of fatty acids and other constituents suggests potential for further seed utilization, particularly through oil recovery. However, compared with the aril, pulp and peel, the available evidence for specific food products based on isolated Gac seeds remains more limited. Seed utilization should therefore presently be regarded as an emerging research area.

Further studies are required to characterize seed composition, oil quality, processing behaviour, stability, safety and potential applications. Establishing these characteristics will be essential for determining whether seed-derived products can become technically and economically viable.

When One Fruit Can Give Several Products

The different characteristics of Gac fruit fractions provide a basis for developing a fraction-specific processing system. Under such a system, the aril could be directed towards high-value carotenoid-rich products, while the pulp and peel could be utilized for powders, natural colourants, extracts and other functional ingredients. Seeds could be considered for oil recovery or other applications as their technological and safety characteristics become better established.

The chemical heterogeneity of Gac supports this approach. Different fractions contain different concentrations and profiles of bioactive compounds; consequently, maximum value may not necessarily be obtained by combining all fractions into a single product. Selective fractionation followed by targeted processing can instead allow the distinctive characteristics of each fraction to be utilized (Kubola and Siriamornpun, 2011; Ariyarathna and Gamage, 2024).

A whole-fruit processing chain can therefore be visualized as: *Whole Gac fruit → fraction separation → aril / pulp / peel / seed → fraction-specific processing → multiple value-added products → reduced processing residues*

From By-product Management to Resource Recovery

The utilization of secondary fruit fractions is increasingly relevant to sustainable food processing. Materials generated during processing may contain carotenoids, phenolics, flavonoids, fatty acids and other constituents that can potentially be recovered and incorporated into value-added products (Ariyarathna and Gamage, 2024).

For Gac, the transition from by-product management to resource recovery involves identifying appropriate applications for pulp, peel and seeds alongside established aril-based products. Increasing the proportion of fruit material entering useful processing streams could reduce the quantity requiring disposal while improving overall raw-material efficiency. Whole-fruit utilization, however, should not simply mean combining all fractions into a single formulation. The more appropriate strategy is selective fractionation and targeted utilization, in which the composition, functionality and technological properties of each fraction determine its most suitable application.

Value Addition and Commercial Potential

The commercial development of Gac depends not only on its nutritional and bioactive composition but also on the ability to convert these characteristics into stable, acceptable and economically viable products. Aril-based products such as powder and oil provide established high-value pathways, while utilization of pulp and peel could provide additional product streams. The development of multiple products from a single fruit could be particularly advantageous for an underutilized crop. Instead of depending on a single aril-based market, processors could develop differentiated products from individual fractions. This could increase raw-material utilization and diversify potential revenue streams.



Processing technologies must also be selected according to the intended product. Technologies designed for carotenoid recovery may differ from those intended to produce whole-fruit powders or composite food ingredients. Consequently, product development should consider not only the concentration of bioactive compounds in the raw material but also their stability during processing and storage.





Potential value-added products from Gac, including beverages, oil and powders.

Future Prospects for Gac Utilization

The future development of Gac processing lies in moving from single-fraction utilization towards an integrated value chain. Further research is required to optimize fraction separation, develop suitable processing technologies and establish the stability, safety and functionality of products derived from individual fractions.

Particular attention should be given to the large-volume pulp fraction and the potential utilization of peel and seeds. Research linking fruit composition with processing conditions, product quality and economic feasibility will be essential for translating laboratory-scale opportunities into commercially viable applications.

The development of small- and medium-scale processing technologies could further support utilization at the production level. Integration of processing with appropriate packaging, storage and market development could help convert Gac from an underutilized fruit into a diversified source of functional food ingredients.

Conclusion

Gac fruit possesses considerable potential beyond its traditionally valued carotenoid-rich aril. The presence of bioactive compounds across the aril, pulp, peel and seed provides a basis

for developing a whole-fruit utilization strategy. Aril-based powders, oils, juices and food products represent established pathways, while pulp and peel offer opportunities for powders, natural colourants and bioactive-rich ingredients. Seed utilization, particularly for oil recovery, represents an additional area requiring further investigation.

The most promising approach is therefore not simply to maximize recovery of one valuable fraction, but to develop fraction-specific processing pathways that utilize the distinctive characteristics of the entire fruit. Such an approach could reduce processing residues, improve raw-material efficiency, diversify product development and strengthen the commercial value chain of Gac.

Thus, whole-fruit utilization has the potential to transform Gac from an aril-dominated commodity into a multi-product horticultural resource, linking sustainable processing, resource recovery and value addition.

GAC AT A GLANCE

Fruit fraction	Potential utilization
Aril	Powder, oil, juice, puree and functional food products
Pulp	Powder, puree, drying formulations and composite products
Peel	Powder, natural colour and bioactive-rich extracts
Seed	Oil and other applications requiring further investigation

References

Ariyarathna, P.M. and Gamage, H.S.D.D. (2024). Gac (Momordica cochinchinensis Spreng.) fruit as a promising functional food: A comprehensive review. International Journal of Science and Research Archive, 11(1), 2227–2236. https://doi.org/10.30574/ijsra.2024.11.1.0299.

Kha, T.C. and Nguyen, M.H. (2022). Gac aril processing technology. In M.H. Nguyen and T.C. Kha (eds.), Gac Fruit: Advances in Cultivation, Utilisation, Health Benefits and Processing Technologies. CABI.

Kubola, J. and Siriamornpun, S. (2011). Phytochemicals and antioxidant activity of different fruit fractions (peel, pulp, aril and seed) of Thai Gac (Momordica cochinchinensis Spreng.). Food Chemistry, 127(3), 1138–1145.

Volume: 06 Issue No: 09

SPRINKLER IRRIGATION: A SUSTAINABLE SOLUTION FOR WATER CONSERVATION IN AGRICULTURE

Article ID: AG-VO6-I09-100

***Shiv Shankar Gope and Yadvendra Pal Singh**

Department of soil science and Agriculture chemistry, School of Agriculture,

Lovely Professional University, Jalandhar, Punjab – 144411, India

*Corresponding Author : Shiv Shankar Gope

Introduction

Water is one of the most important resources required for agriculture. A large part of agricultural production depends on irrigation, especially in areas where rainfall is uncertain or insufficient. However, traditional irrigation methods can sometimes result in considerable water loss through runoff, evaporation, and deep percolation. With increasing pressure on groundwater and changing climatic conditions, farmers need irrigation methods that can use water more efficiently.

Sprinkler irrigation is one such method. It is an irrigation system in which water is supplied to crops in the form of small droplets, similar to natural rainfall. The system uses pipes, pumps, valves, and sprinkler devices to distribute water over the agricultural field. When properly designed and managed, sprinkler irrigation can reduce water wastage and provide more uniform irrigation to crops.

How Sprinkler Irrigation Works

In a sprinkler irrigation system, water is pumped from a source such as a tube well, farm pond, reservoir, or other water storage structure. The water passes through a network of pipes and reaches the sprinklers installed at different locations in the field. Pressure created by the pump forces water through small openings in the sprinkler heads, producing a spray of fine droplets.

The sprinklers are generally operated for a specific period depending on the crop, soil type, weather conditions, and water requirement. After one area receives sufficient water, the

sprinklers can be shifted to another location in a manually operated system. In modern systems, valves and controllers can also be used to automate irrigation.

Role in Water Conservation

The major advantage of sprinkler irrigation is its ability to apply water more efficiently than some traditional surface irrigation methods. In flood or uncontrolled surface irrigation, water may accumulate in certain areas while other parts of the field receive less water. This can lead to runoff and unnecessary water losses. Sprinkler irrigation distributes water over the field in a controlled manner. The application rate can be adjusted according to the infiltration capacity of the soil. This is particularly useful for soils where water infiltration is relatively slow and surface runoff is a concern. Another important benefit is that sprinkler irrigation can be used to irrigate uneven or undulating land without requiring extensive land levelling. It can therefore be useful in areas where conventional surface irrigation is difficult to manage.

Benefits for Farmers

Sprinkler irrigation can provide several benefits apart from water conservation. It can improve the uniformity of water application and help maintain suitable soil moisture around the crop root zone. Better moisture management may support healthy crop growth and reduce the stress caused by irregular irrigation. The system can also save labour in comparison with certain traditional irrigation practices, particularly when it is combined with automation. Sprinklers can be used for many crops, including vegetables, pulses, oilseeds, cereals, fodder crops, and some fruit crops. Another useful feature is that soluble fertilizers and certain crop protection materials can sometimes be applied through suitable sprinkler systems. This practice, when properly managed, can improve the efficiency of input application.

Limitations of Sprinkler Irrigation

Although sprinkler irrigation has many advantages, it is not suitable for every situation. The initial installation cost can be higher than that of simple surface irrigation. Farmers also need a reliable source of water and sufficient pressure to operate the system. Wind can affect the distribution of water droplets and reduce the uniformity of irrigation. High temperatures and low humidity can also increase evaporation losses during sprinkler operation. Therefore, irrigation should preferably be scheduled during suitable periods, such as early morning or evening, depending on local weather conditions. Maintenance is another important consideration. Sprinkler nozzles may become blocked because of sediments or impurities in the irrigation

water. Regular cleaning of filters, pipes, and sprinkler heads is therefore necessary for proper performance.

Sprinkler Irrigation and Sustainable Agriculture

Sustainable agriculture aims to increase food production while conserving natural resources. Efficient irrigation is an important part of this approach. By applying water according to crop requirements, sprinkler irrigation can help reduce unnecessary water use and support better management of available water resources. The importance of such systems is increasing as many agricultural regions face groundwater depletion and irregular rainfall. Sprinkler irrigation can be combined with soil moisture sensors, weather information, automatic controllers, and solar-powered pumping systems to make irrigation more precise and energy efficient.

Future Scope

The future of sprinkler irrigation is closely connected with precision agriculture. Sensor-based systems can monitor soil moisture and help determine when irrigation is actually required. Automated controllers can then operate the irrigation system according to predefined conditions.

Solar-powered irrigation systems also offer opportunities for farmers in areas where electricity supply is unreliable. Combining solar energy with efficient sprinkler systems can reduce dependence on conventional energy sources. Research and development in sprinkler design may further improve water distribution and reduce losses caused by evaporation and wind. Affordable and easy-to-maintain systems will be particularly important for small and marginal farmers.

Conclusion

Sprinkler irrigation is an important technology for improving the efficiency of agricultural water use. By applying water in the form of controlled droplets, it can provide relatively uniform irrigation and reduce some of the losses associated with conventional irrigation methods. Despite challenges such as installation cost, wind effects, and maintenance requirements, proper design and management can make sprinkler irrigation a useful option for many agricultural situations. With increasing water scarcity and growing demand for food production, efficient irrigation technologies will play an important role in the future of agriculture. Sprinkler irrigation, especially when combined with automation, sensors, and renewable energy, can contribute to more efficient and sustainable use of water on farms.

Volume: 06 Issue No: 09

FROM FARM TO BRAND: HOW ITC USES AGRICULTURAL SUPPLY CHAINS AS A MARKETING ADVANTAGE

Article ID: AG-VO6-I09-101

Sivakumar K

XIME, Chennai, Tamil Nadu, India

Abstract

ITC Limited is usually studied either as an FMCG company or as an agribusiness pioneer through e-Choupal. This article argues that the two are linked: ITC's farm-level sourcing capabilities work as a marketing asset for its food brands. Drawing on ITC's FY2025-26 disclosures, peer-reviewed research on e-Choupal, and concepts from value chain analysis, the resource-based view and relationship marketing, it traces how procurement, crop development and digital farmer platforms feed into quality consistency, traceability, cost, innovation and brand credibility. The advantage is strongest where the agricultural input defines the product, as with Aashirvaad atta, and weaker where brand equity rests on flavour or format. The article also sets out the limits: evidence on farmer benefit is mixed, much impact data is company-reported, and consumers do not reliably reward sustainability claims. A supply chain becomes a marketing capability only when its effects are visible to buyers, hard to copy and credibly verified.

Keywords: agricultural supply chain; farm-to-brand; ITC Limited; e-Choupal; ITCMAARS; resource-based view; traceability

1. Introduction

ITC Limited is a diversified Indian conglomerate spanning cigarettes, packaged foods, personal care, paperboards and agribusiness. Its FMCG-Others segment, home to Aashirvaad, Sunfeast and Bingo!, grew segment revenue by 10.1% in FY2025-26, while its Agri Business segment runs one of India's larger commodity sourcing and export operations (ITC Limited [ITC], 2026).

For a food company, the agricultural supply chain is not a back-office function. Wheat, potatoes, spices and milk are the product. Their quality, cost and consistency shape what a

consumer tastes, pays and trusts. In India this link is hard to manage because production is fragmented: small and marginal holdings under two hectares make up about 86% of operational holdings, and the average holding is 1.08 hectares (Department of Agriculture, Cooperation & Farmers Welfare [DAC&FW], 2019).

This article uses "farm-to-brand" for the capabilities that connect farm-level sourcing to a consumer-facing brand promise. The research question is: **how can ITC convert agricultural supply-chain capabilities into a marketing advantage?** The argument is conditional. Sourcing becomes a marketing asset when it creates a difference the consumer can perceive, when rivals cannot easily copy it, and when the claim can be verified. These conditions echo the resource-based view, which locates lasting advantage in resources that are valuable, rare and hard to imitate (Barney, 1991).

2. ITC's Agribusiness and Agricultural Linkages

ITC's Agri Business handles roughly four million tonnes a year across 22 states and more than 20 agricultural value chains (The CSR Universe, 2026). It is the largest Indian exporter of unmanufactured leaf tobacco and a leading exporter of spices and coffee. Its value-added agri products portfolio, which spans spices, coffee, frozen marine and horticulture products, grew about 1.4 times over two years (ITC, 2026).

Farmer linkages have evolved in two waves. The first was e-Choupal, launched in 2000 for soybean in Madhya Pradesh. ITC reports about 6,100 village internet kiosks serving over four million farmers in more than 35,000 villages across 10 states (ITC, n.d.-a). These are long-standing company figures, not recent audited counts. The second wave is ITCMAARS, a crop-agnostic digital platform delivered through Farmer Producer Organisations (FPOs) in 11 states. ITC's FY2025-26 results statement puts the network at over 2,100 FPOs and about 2.3 million farmers (ITC, 2026); press coverage of the annual report cites more than 2.6 million (The CSR Universe, 2026). The gap likely reflects different reporting dates, and it shows why such figures should be read as indicative.

Aggregation is where sourcing meets the brand. ITC reports that direct FPO sourcing through ITCMAARS now covers about 40% of the wheat bought for Aashirvaad atta and Agri Business (ITC, 2026). The company also describes its capability as traceable, attribute-based and identity-preserved sourcing (ITC, 2026). This is a company claim. Independent evidence exists mainly for the early e-Choupal period (Goyal, 2010), and it is discussed in Section 5.

3. From Agricultural Procurement to Brand Creation

Porter's (1985) value chain treats inbound logistics and operations as sources of differentiation, not only cost. ITC's food business illustrates this: the upstream stages decide what the brand can credibly promise downstream.

Aashirvaad is the clearest case. A 2024 Business Standard report notes that ITC built Aashirvaad, now a brand of over Rs 6,000 crore, by sourcing wheat directly from farmers (Press Trust of India, 2024). ITC says its sourcing network, crop development and digital tools secure wheat of the specific grades the atta portfolio needs (ITC, 2026). Because atta is essentially processed grain, consistent grain means a consistent chapati, which is the brand promise. That base has also supported extensions such as Multigrain, Select and High Protein atta; value-added variants and adjacencies now make up about 16% of the Aashirvaad staples portfolio (ITC, 2026).

Bingo! shows a partial link. ITC acquired Technico, a seed-potato technology company, and Technico supports production and procurement of chip-grade potatoes from farmers for Bingo! (FreshPlaza, 2021; ITC, n.d.-b). Controlling seed helps secure a processing-grade raw material, but the consumer buys Bingo! for flavour and format, so the farm link is mostly invisible.

Sunfeast shows a weak link. Biscuits use flour, sugar and fats bought largely as commodities. Its growth comes from product and brand propositions, such as Dark Fantasy's premium position (ITC, 2026), not from sourcing. Newer lines sit closer to the farm: Aashirvaad Svasti draws on a farmer milk procurement network in Bihar, West Bengal and Jharkhand, and spice sourcing is being scaled for Sunrise and Aashirvaad spices (ITC, 2026).

Table 1. Strength of the farm-to-brand link by brand

Brand	Critical farm input	Reported upstream link	Visibility to consumer (author's assessment)
Aashirvaad atta	Wheat	About 40% of wheat via ITCMAARS FPOs; grade-specific crop development	High: the product is the grain
Aashirvaad Svasti	Milk	Farmer milk	High: freshness and

Brand	Critical farm input	Reported upstream link	Visibility to consumer (author's assessment)
		procurement network in three eastern states	purity
Sunrise and Aashirvaad spices	Chilli, turmeric and other spices	Spice sourcing scaled for the brands	Medium to high
Bingo!	Chip-grade potato	Technico seed; chip-stock procurement from farmers	Low to medium
Sunfeast	Wheat flour, sugar, fats	Mostly commodity purchase	Low

Sources: ITC (2026); FreshPlaza (2021). The last column is analytical judgement.

The pattern suggests a simple rule: the more the agricultural input *is* the product, the more sourcing can become marketing.

4. How Supply Chain Becomes a Marketing Advantage

Five mechanisms connect ITC's sourcing capabilities to market outcomes. Table 2 summarises each chain; the text below explains where it is strong and where it is conditional.

Table 2. From supply-chain capability to business impact

Mechanism	Supply-chain capability	Marketing implication	Consumer value	Potential business impact
Quality consistency	Grade-specific wheat sourcing and crop development	A repeatable product claim	Same taste and texture every pack	Repeat purchase; defensible price point
Traceability	Identity-preserved lots; FPO-level digital records	Provenance and compliance claims	Assurance on origin and safety	Export access; organic and premium tiers
Cost efficiency	Direct FPO	Room to fund	Better value per	Margin

Mechanism	Supply-chain capability	Marketing implication	Consumer value	Potential business impact
	sourcing; less intermediation	brand investment or hold price	rupee	resilience in inflationary years
Product innovation	Agronomy, seed and grain know-how	Variant-led extensions	Health and nutrition choices	Premiumisation; new categories
Trust and credibility	Long farmer relationships at scale	A believable "sourced from Indian farms" story	Confidence in the brand's integrity	Brand equity; licence to operate

5. e-Choupal and Digital Agribusiness Marketing

What e-Choupal does. Each kiosk is a village computer run by a local farmer, the sanchalak, who helps others check prices, weather and crop advice and earns a commission on transactions (World Business Council for Sustainable Development, n.d.). Farmers can sell directly to ITC at hubs as an alternative to the regulated mandi, and ITC describes the network as a two-way channel that also carries goods and services into villages (ITC, n.d.-a).

What the evidence shows. Goyal (2010) found that kiosks in Madhya Pradesh raised average mandi soybean prices by about 1.7% and reduced price dispersion across mandis, and that area under soybean increased. Kumar (2014) offers a more critical view: because Malwa's farmers and traders are price takers in a global soybean market, price information had negligible effect on the final price farmers received, and "disintermediation" largely replaced traditional intermediaries with a more corporatised one. Her work also highlights that whoever sets quality norms holds real power in the exchange.

Interpretation: why it matters for marketing. Read together, these studies suggest e-Choupal's lasting value to ITC lies less in price transparency and more in relationships and information. Four effects stand out, though each is an analytical inference rather than a measured outcome:

- **Reduced information asymmetry** gave ITC a trusted role in farmers' decisions, the basis for commitment in relationship marketing (Morgan & Hunt, 1994).

- **Participation through sanchalaks** embedded the platform in village social networks, which is harder to copy than technology.
- **Market intelligence** on crops, quality and rural demand flows back to ITC, informing both sourcing and rural marketing.
- **Potential network effects** arise as more farmers improve data and scale, which attracts service partners, which in turn draws more farmers. ITCMAARS extends this logic by working through FPOs and offering advisory, inputs, credit and market linkage in one app (ITC, 2026).

The early evidence of outcomes from ITCMAARS is encouraging but thin. An AI advisory pilot with the Department of Science and Technology in Varanasi reported yield gains of around 15% and net returns up nearly 30% among adopting wheat farmers (The CSR Universe, 2026). These figures come from assessments cited by the company and cover about 27,000 farmers, so they cannot yet be generalised.

6. Challenges and Limitations

The farm-to-brand model faces structural, commercial and evidential limits.

Fragmentation and quality variance. With most holdings under two hectares (DAC&FW, 2019), every tonne of consistent wheat must be assembled from many small lots. FPOs reduce the number of counterparties, but quality still varies by farm, season and region, and grading at scale is costly.

Climate and policy volatility. ITC itself flags El Niño risk to the monsoon (ITC, 2026). Government stock limits and export restrictions, along with foreign tariffs, can switch sourcing economics abruptly, as the Agri segment's weak FY2025-26 showed.

Traceability at smallholder scale. Recording farm-level data for millions of plots is far harder than for a few large estates. A traceability claim is only as strong as its weakest record.

Digital adoption. e-Choupal needed a human operator in every village, and ITCMAARS relies on FPOs as a "phygital" layer. This suggests that app-only models reach fewer farmers than headline registrations imply.

Imitability. Rivals can buy similar wheat from mandis or government stocks, and several large FMCG firms also sell branded atta. ITC's edge lies in the depth of its relationships and data, not in exclusive access to grain.

Farmer welfare versus commercial goals. Kumar (2014) shows that information alone does not shift bargaining power when farmers are price takers. If sourcing benefits flow mostly to the company, the "farmer partnership" narrative becomes fragile.

Evidence quality. Most recent impact figures are company-reported or company-commissioned. Independent, peer-reviewed evaluation of ITCMAARS does not yet exist in the published literature this article reviewed.

8. Strategic Implications

The ITC case offers lessons for ITC and for other agribusiness and FMCG firms.

1. **Start where the input is the product.** Staples, dairy, spices and fresh produce reward sourcing investment most; snacks and biscuits reward it least.
2. **Carry traceability to the pack.** Farm-level data creates consumer value only when it is shown, for example through batch-level origin information, and verified by a third party.
3. **Build platforms around institutions.** Digital farmer platforms scale faster when anchored in FPOs or local operators than as stand-alone apps.
4. **Use data for sourcing agility.** Farm and FPO data can guide where and when to buy, reducing the cost and quality shocks that weaken brands.
5. **Build premium tiers on provenance.** Organic, high-protein or region-specific variants can command higher prices if the sourcing behind them is exclusive and documented.
6. **Tell farm-to-consumer stories with evidence.** A claim of direct farmer sourcing should come with measurable farmer outcomes, ideally assessed independently, or it will read as ordinary advertising.
7. **Share value visibly with farmers.** Durable supplier loyalty, and a credible brand story, both depend on farmers seeing a real benefit from the relationship.

Conclusion

Can ITC convert agricultural supply-chain capabilities into a marketing advantage? The evidence suggests yes, but selectively. In Aashirvaad atta, direct wheat sourcing, crop development and FPO-based procurement shape the very attributes consumers judge the brand on, and the brand's scale and extensions reflect that. In Bingo! and Sunfeast, the same capabilities mostly lower cost and secure supply; they matter operationally but are not what the consumer buys.

Three conditions separate a marketing capability from an operational function. First, **perceptibility**: the upstream difference must show up in something the consumer or business buyer can notice, such as consistency, freshness or certified origin. Second, **inimitability**: the advantage must rest on relationships, data and know-how built over decades, which is where e-Choupal's real legacy lies, rather than on commodity access that rivals can buy. Third, **verifiability**: claims about farmers and sustainability must be backed by traceable records and independent evidence, because trust built on unverified claims is easily lost.

ITC meets the first two conditions strongly in staples and is still building the third. Its next source of advantage is likely to come not from sourcing more, but from proving more: turning farm-level data into evidence that consumers, buyers and farmers can all see.

References

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management, 17*(1), 99-120. https://doi.org/10.1177/014920639101700108

Department of Agriculture, Cooperation & Farmers Welfare. (2019). *All India report on agriculture census 2015-16*. Government of India. https://www.fao.org/fileadmin/templates/ess/ess_test_folder/World_Census_Agriculture/WCA_2020/WCA_2020_new_doc/IND_REP_ENG_2015_2016.pdf

FreshPlaza. (2021, July 6). *Technico changing potato value chain in India and beyond*. https://www.freshplaza.com/asia/article/9336947/technico-changing-potato-value-chain-in-india-and-beyond/

Global Agriculture. (2026, July 1). *ITC Climate Smart Agriculture programme delivers 23% higher farmer income and 20% lower production costs*. https://www.global-agriculture.com/mechanization-technology/itc-climate-smart-agriculture-programme-delivers-23-higher-farmer-income-and-20-lower-production-costs/

Goyal, A. (2010). Information, direct access to farmers, and rural market performance in Central India. *American Economic Journal: Applied Economics, 2*(3), 22-45. https://doi.org/10.1257/app.2.3.22

ITC Limited. (2026, May 21). *Media statement: Financial results for the quarter and year ended 31st March, 2026*. https://itcportal.com/media-centre/press-releases/media-statement-financial-results-for-the-quarter-and-year-ended-31st-march-2026.html

ITC Limited. (n.d.-a). *ITC e-Choupal*. Retrieved September 30, 2026, from https://itcportal.com/itc-businesses/agri-business/itc-e-choupal.html

ITC Limited. (n.d.-b). *Agri business*. Retrieved September 30, 2026, from https://itcportal.com/itc-businesses/agri-business.html

Kumar, R. (2014). Elusive empowerment: Price information and disintermediation in soybean markets in Malwa, India. *Development and Change*, *45*(6), 1332-1360. https://doi.org/10.1111/dech.12131

Morgan, R. M., & Hunt, S. D. (1994). The commitment-trust theory of relationship marketing. *Journal of Marketing, 58*(3), 20-38. https://doi.org/10.1177/002224299405800302

Porter, M. E. (1985). *Competitive advantage: Creating and sustaining superior performance*. Free Press.

Press Trust of India. (2024, December 5). ITC to increase FPOs to 4,000 in next 4 years linking one crore farmers. *Business Standard*. https://www.business-standard.com/companies/news/itc-to-increase-fpos-to-4-000-in-next-4-years-linking-one-crore-farmers-124120500607_1.html

Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production, 16*(15), 1699-1710. https://doi.org/10.1016/j.jclepro.2008.04.020

Volume: 06 Issue No: 09

MILLETS: FROM TRADITIONAL GRAINS TO MODERN SUPERFOODS

Article ID: AG-VO6-I09-102

Shiyamala S

Department of Agricultural Engineering, Kalasalingam Academy of Research and Education, Virudhunagar, Tamil Nadu, India

Introduction

Millets are among the oldest cultivated cereal crops and have traditionally formed an important component of diets in Asia and Africa. In India, millets have been cultivated and consumed for centuries, particularly in regions characterised by low and erratic rainfall. Their ability to grow under relatively harsh agro-climatic conditions, coupled with their nutritional attributes, has contributed to their importance in traditional food systems. During the period of rapid agricultural modernisation, the cultivation and consumption of several millet species declined as rice and wheat became increasingly dominant in food systems. However, growing concerns regarding nutritional security, dietary diversification, climate resilience and sustainable agriculture have renewed interest in these traditional cereals. Today, millets are undergoing a significant transition from traditional staple foods to ingredients for a diverse range of modern food products. Advances in food processing, product development and value addition are creating new opportunities for millets in both domestic and international markets. Consequently, millets are increasingly being recognised not merely as traditional grains but as potential components of sustainable and diversified food systems.

Millets: A Diverse Group of Nutritious Cereals

The term millet represents a group of small-seeded cereals belonging to different genera. Important millets cultivated in India include pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), little millet (*Panicum sumatrense*), kodo millet (*Paspalum scrobiculatum*), barnyard millet (*Echinochloa spp.*) and proso millet (*Panicum miliaceum*). Although these crops are collectively referred to as millets, their nutritional

composition and functional properties vary considerably. Millets generally provide carbohydrates as the major energy source and contribute dietary fibre, protein, minerals and various bioactive compounds. Finger millet, for example, is particularly recognised for its calcium content, whereas pearl millet contributes appreciable amounts of protein, iron, zinc and other nutrients.

Millets also contain phytochemicals such as phenolic compounds and other antioxidant constituents. However, the nutritional value of millet-based foods depends not only on the grain species but also on processing conditions, variety, cultivation environment and method of preparation. Therefore, the nutritional potential of millets should be considered from a broader perspective rather than simply categorising them as a single group of "superfoods."

Traditional Importance and Changing Consumption Patterns

- Traditional millet-based foods reflect the close relationship between agricultural practices, local environments and dietary culture. Across different regions of India, millets have traditionally been consumed as porridges, flatbreads, fermented foods, steamed products and rice substitutes.
- Finger millet has long been associated with products such as *ragi mudde*, porridge and malt-based preparations. In contrast, pearl millet is traditionally consumed in the form of *bajra roti* and other regional foods. Small millets have also been used in traditional rice-substitute preparations and porridges.
- However, changes in food preferences, urbanisation, agricultural policies, market availability and the increasing consumption of refined cereals contributed to a decline in the dietary share of several traditional grains.
- The current resurgence of interest in millets represents an important shift in this trend. Consumers are increasingly seeking diversified diets containing whole grains, dietary fibre and nutrient-dense ingredients.

Nutritional Significance of Millets

The nutritional characteristics of millets are a major factor in their renewed popularity. Their dietary fibre content can improve dietary quality, while their mineral and micronutrient composition makes them valuable components of diversified diets. Millets are naturally gluten-free, making them suitable for individuals who need to avoid gluten-containing cereals.

However, gluten-free status alone does not necessarily make a food nutritionally superior; the overall formulation and processing method remain important.

The presence of phenolic compounds and other bioactive components has also generated considerable research interest. These compounds may contribute to antioxidant activity, although their concentrations and bioavailability can vary with millet species and processing conditions. Another important consideration is the presence of antinutritional factors such as phytates and tannins in certain millet varieties. These compounds can influence mineral bioavailability and other nutritional properties. Appropriate processing techniques, including soaking, germination, fermentation and thermal processing, can modify these components and improve the functional characteristics of millet-based foods. Thus, the nutritional potential of millets should be evaluated in conjunction with appropriate processing and product formulation.

Food Processing: Converting Potential into Products

The transition of millets from traditional grains to modern food ingredients is strongly dependent on processing technology. Unlike polished rice or refined wheat products, whole millet grains can present challenges associated with dehulling, milling, flour functionality, storage stability and product quality. The basic processing sequence generally involves cleaning, grading, dehulling where required, milling and packaging. Further processing can include malting, fermentation, extrusion, flaking, popping and thermal treatment. These technologies can significantly modify the physical, nutritional and functional properties of millet ingredients.

Milling and Flour Production

Milling is one of the most important operations in millet utilisation. Millet flour can serve as a raw material for bakery products, traditional foods, snacks and composite flour formulations. Milling conditions influence particle size, water absorption, pasting characteristics and the final quality of the product.

Malting and Germination

Malting or germination can induce biochemical changes within the grain. Enzymatic activity during germination may influence starch, protein and phytochemical characteristics. Malted millet ingredients are particularly relevant for beverages, complementary foods and breakfast formulations.

Fermentation

Fermentation has traditionally been used in several cereal-based foods.

In millet processing, fermentation can modify flavour, texture, acidity and certain nutritional characteristics. It can therefore contribute to the development of improved sensory and functional properties.

Extrusion

Extrusion is an important modern processing technology for millet-based convenience foods. It can be used to produce ready-to-eat snacks, breakfast cereals and expanded products. Processing conditions such as temperature, moisture and screw speed influence expansion, texture and nutritional characteristics.

Value-Added Food Products

The growing interest in millets has expanded their application beyond conventional preparations. Millet-based products are increasingly being developed in categories such as bakery products, breakfast cereals, snacks, instant mixes, noodles, pasta, beverages and ready-to-cook foods. Composite flour technology is particularly important because the functional limitations of millet flour can sometimes be addressed by blending it with other cereal or non-cereal ingredients. Such formulations can improve dough handling, texture, nutritional balance and consumer acceptability. The development of value-added products also provides an opportunity to increase the economic value of millet grains. Instead of marketing millets exclusively as raw or minimally processed grains, processors can develop differentiated products targeted at specific consumer groups.

For example, products can be designed for:

- Health-conscious consumers
- Urban working populations
- Children and young consumers
- Institutional food programmes
- Convenience-food markets
- Sports and wellness segments
- Gluten-free food markets

However, successful product development requires a balance between nutritional quality, sensory acceptance, processing feasibility, shelf life and cost.

Millets and Sustainable Agriculture

The renewed interest in millets is also associated with their potential contribution to

sustainable agriculture. Many millet species are adapted to semi-arid and dryland environments and can perform under relatively limited water availability compared with some major cereal crops, although actual resource requirements vary with crop, cultivar, soil and production conditions. Their integration into diversified cropping systems can contribute to greater crop diversity and provide additional food and livelihood options for farming communities. Nevertheless, millets should not be viewed as a universal replacement for rice or wheat. Sustainable food systems require crop diversification based on regional agroecological conditions, nutritional requirements, market demand and farmer profitability. The significance of millets therefore lies in their potential contribution to a **diversified and resilient agricultural system** rather than their ability to replace existing staple cereals completely.

Opportunities for Entrepreneurship and Rural Development

- The expansion of millet-based food markets can generate opportunities across the value chain. Farmers, primary processors, milling enterprises, food manufacturers, startups and retailers can participate in different stages of value addition.
- Small and medium-scale enterprises can explore opportunities in millet flour production, ready-to-cook mixes, bakery products, snacks, breakfast cereals and traditional-food-based products.
- Processing at the local or regional level can also reduce the distance between producers and consumers while creating employment opportunities. However, the development of a sustainable millet-processing sector requires reliable raw material supply, appropriate processing infrastructure, quality control, packaging, market access and consumer awareness.
- For entrepreneurs, innovation should therefore focus not only on introducing new millet products but also on improving processing efficiency, product consistency, shelf life and affordability.

From Traditional Grain to Modern Food Ingredient

The transformation of millets is not simply a return to traditional food habits. It represents the integration of traditional knowledge with modern science and food technology. Traditional communities established diverse ways of cultivating, processing and consuming millets according to local conditions. Modern research now provides opportunities to characterise their nutritional and functional properties and develop technologies for improved

utilisation. This combination offers considerable potential. A traditional millet grain can become a modern breakfast cereal, a convenient ready-to-cook product, a bakery ingredient or a functional food component. Such transformation can increase the value of the crop while creating new markets for producers and processors.

Conclusion

Millets represent an important link between traditional agricultural knowledge and the emerging demand for diversified, nutritious and sustainable foods. Their historical importance demonstrates their adaptability to different environments and food cultures, while modern food processing has created new opportunities for their utilisation. The transition from traditional millet foods to modern millet-based products is being driven by advances in processing technology, changing consumer preferences, interest in dietary diversification and the need for resilient food systems. The future of millets therefore lies not simply in returning to the past, but in **reinterpreting traditional grains through modern science, technology and entrepreneurship**. From traditional kitchens to modern processing industries, millets are entering a new phase of development. Their continued growth will depend on how effectively the food sector can combine **nutritional value, technological innovation, consumer acceptance and sustainable production**.

Millets may be ancient grains, but their potential applications belong very much to the future.

Volume: 06 Issue No: 09

POSTBIOTICS: AN EMERGING SUSTAINABLE ALTERNATIVE TO ANTIBIOTICS IN POULTRY PRODUCTION

Article ID: AG-VO6-I09-103

Stephen Soren

Department of Animal Nutrition, West Bengal University of Animal and Fishery Sciences, Kolkata-700037, West Bengal, India

Abstract

The poultry industry is increasingly seeking safe and sustainable alternatives to antibiotic growth promoters. Postbiotics—preparations of inanimate microorganisms and/or their components that confer a health benefit on the host—have emerged as a promising option because they can retain biological activity without requiring viable microbial cells. Recent poultry studies indicate that postbiotics derived from *Lactobacillus spp*. and *Saccharomyces cerevisiae* fermentation products can improve feed efficiency, modulate gut microbiota, support intestinal morphology and barrier function, influence immune responses, and improve selected blood biochemical indices. Research from broiler and Rainbow Rooster chickens further demonstrates that postbiotic responses depend on microbial strain, dose, formulation, production environment and challenge status. This article summarizes the concept, mechanisms, recent evidence, practical advantages, limitations and future prospects of postbiotics as tools for antibiotic-responsible poultry production.

Keywords: postbiotic; poultry; gut health; feed efficiency; Lactobacillus; antibiotic alternative

Introduction

The poultry industry has traditionally used antibiotic growth promoters (AGPs) to improve feed utilization and reduce the impact of enteric microorganisms. However, concern regarding antimicrobial resistance and antibiotic residues has intensified the search for nutritional alternatives that can maintain productivity while supporting animal and public health. Probiotics, prebiotics, organic acids, phytobiotics, enzymes and synbiotics have received considerable attention, and postbiotics have recently emerged as another promising approach.[1,2]

The International Scientific Association for Probiotics and Prebiotics defines a postbiotic as a preparation of inanimate microorganisms and/or their components that confers a health benefit on the host.[3] Unlike probiotics, postbiotics do not depend on the survival of viable microorganisms during feed manufacture, storage or passage through the gastrointestinal tract. This feature can offer practical advantages in stability, handling and product standardization. Postbiotics may contain inactivated microbial cells, cell-wall fragments, peptidoglycans, teichoic acids, exopolysaccharides, proteins and other microbial structures. Fermentation-associated metabolites such as organic acids, peptides and enzymes may also remain in the preparation. Their biological effects therefore depend on the microbial strain, fermentation conditions, inactivation process, dose and route of administration.[1],[3]

Why Are Postbiotics Important in Poultry?

Live probiotics can be highly beneficial, but their efficacy may be influenced by viability during processing and storage. Postbiotics remove the requirement for microbial viability while retaining bioactive microbial components. This makes them particularly attractive for poultry systems in which feed processing, temperature, moisture and storage conditions can reduce the survival of live cultures. An early poultry-focused review by Soren et al. described the potential of Saccharomyces cerevisiae-derived postbiotics to influence growth, gastrointestinal microbiota, intestinal development and immune responses.[4] Subsequent controlled experiments have provided stronger evidence that selected postbiotic preparations can improve biological efficiency and gut health, although responses are not uniform across all products.

How Do Postbiotics Work?

Modulation of gut microbiota: Organic acids and other microbial products may create conditions that suppress undesirable bacteria while favouring beneficial populations. Postbiotic-associated antimicrobial compounds can also directly inhibit selected enteric pathogens. In broilers, reductions in Escherichia coli and Salmonella have been reported with both yeast- and Lactobacillus-derived preparations.[5],[6]

Improvement of intestinal morphology: Villus height and the villus-height-to-crypt-depth ratio are useful indicators of intestinal absorptive capacity. Selected postbiotics have increased villus height or improved VH:CD ratio, potentially increasing the functional surface available for nutrient absorption.[5],[7]

Support of intestinal barrier function: Microbial cell components can interact with intestinal epithelial and immune receptors and may influence tight-junction integrity. A more effective epithelial barrier can limit excessive passage of luminal antigens and reduce the metabolic cost associated with persistent intestinal inflammation.[1]

Immunomodulation: Postbiotics can interact with innate immune pathways without requiring microbial replication. Responses vary with the preparation and health status of the birds. Some poultry studies report improved vaccine antibody responses or other immune indices, while others show little change under good husbandry conditions.[5],[6]

Effects on metabolism and oxidative balance: Selected preparations have been associated with lower serum cholesterol and improved antioxidant status. These responses may involve microbial metabolites, bile-acid metabolism and improved intestinal homeostasis.[5],[7]

Recent Evidence from Poultry Studies

Soren et al. evaluated a Saccharomyces cerevisiae fermentation product (SCFP) at 1.25 kg/MT feed in Ven Cobb 400 broilers. The SCFP improved feed conversion over the complete experimental period, reduced serum cholesterol and corticosterone, lowered populations of several pathogenic or antimicrobial-resistant Gram-negative bacteria, and improved villus measurements and antibody titres compared with the control.[5] These findings demonstrate that a yeast fermentation product can influence both production efficiency and gut-health-related traits. Work with Lactobacillus DH42 has extended this concept to species-specific bacterial preparations. Seikh et al. compared viable Lactobacillus DH42 with its inactivated postbiotic in commercial broilers. The postbiotic group showed higher final body weight and average daily gain with favourable feed conversion, while serum cholesterol was reduced in the postbiotic, probiotic and antibiotic groups relative to the control.[8] Soren et al. subsequently evaluated an inactivated Lactobacillus rhamnosus NCDC 298 preparation supplied at 1 mL/bird/day in drinking water.

Overall FCR improved relative to both control and antibiotic groups. Caecal E. coli and Salmonella counts were reduced, whereas Lactobacillus counts increased.[6] The study also recorded a higher Newcastle disease vaccine antibody titre on day 28, although several other immune measurements did not differ. More recently, Raj et al. investigated Lactobacillus DH42 probiotic and postbiotic preparations in Rainbow Rooster chickens. Average daily gain was not significantly altered, but both microbial treatments reduced feed intake during the finisher and

overall periods and improved FCR. The postbiotic increased villus height in the jejunum and ileum, while probiotic and postbiotic supplementation increased the duodenal VH:CD ratio. Serum cholesterol was also reduced.[7] This study is particularly relevant because it demonstrates that improved feed utilization and intestinal health can occur even when growth rate remains unchanged. Together, these studies show why postbiotic efficacy should be interpreted at the level of the specific strain and preparation. Some preparations mainly improve feed efficiency, whereas others produce stronger effects on microbiota, morphology, immunity or blood metabolites.

Postbiotics versus Probiotics: Practical Considerations

Feature	Probiotic	Postbiotic
Microbial state	Viable microorganisms	Inactivated microorganisms/components
Viability during storage	Essential	Not required
Sensitivity to feed processing	May be high	Potentially lower
Main quality concern	Identity and viable count	Identity, inactivation and composition
Practical potential	Established	Rapidly emerging
Major research need	Consistent field efficacy	Standardization and dose optimization

Role in Antibiotic-Responsible Poultry Production

Postbiotics should not be regarded as a universal one-for-one substitute for antibiotics. Their most appropriate role is within an integrated gut-health programme that combines balanced nutrition, clean drinking water, vaccination, biosecurity, litter management, disease monitoring and appropriate veterinary care. When these fundamentals are in place, postbiotics may help maintain intestinal function and feed efficiency while reducing reliance on non-therapeutic antimicrobial inputs. The practical advantage of postbiotics may become particularly important under enteric challenge. Stabilized non-viable Lactobacilli have been reported to support health, performance and gut status in challenged broilers, reinforcing the concept that microbial viability is not essential for all beneficial effects.[9]

Challenges and Future Prospects

Despite rapid progress, several limitations must be addressed before postbiotics can be used consistently across poultry production systems. Products currently described as postbiotics differ greatly in microbial strain, fermentation medium, biomass concentration, inactivation method, metabolite profile, carrier, dose and administration route. Consequently, results obtained with one preparation should not automatically be extrapolated to another.

Future studies should clearly report microbial identity, fermentation conditions, inactivation procedures, confirmation of non-viability, composition, storage stability and exact dose. Comparative studies of liquid and dry formulations are also needed. Drying technologies may simplify storage and feed incorporation, whereas liquid preparations can be conveniently delivered through drinking water. Another important development will be the use of microbiome sequencing, metabolomics, proteomics and host gene-expression analysis to identify the components responsible for particular biological responses. This may allow the development of precision postbiotics designed for defined objectives such as pathogen control, improved feed conversion, intestinal barrier support or immune modulation.

Combinations of postbiotics with prebiotics, phytobiotics, organic acids or enzymes may provide complementary effects, but claims of synergy should be supported by properly designed experiments. Economic evaluation under commercial conditions will also be essential before widespread adoption.

Conclusion

Postbiotics represent a promising next generation of microbial feed technology for poultry. Evidence from Saccharomyces cerevisiae fermentation products and Lactobacillus-derived preparations indicates potential benefits for feed efficiency, gut microbial balance, intestinal morphology, selected immune responses and lipid metabolism. Their lack of dependence on viable microbial cells offers practical advantages for manufacture, storage and administration. Nevertheless, postbiotic responses are strain-, process-, dose- and environment-dependent. Future progress will require better product characterization, standardized reporting, dose-response studies and commercial-scale validation. Used as part of an integrated gut-health programme, well-characterized postbiotics could contribute meaningfully to sustainable and antibiotic-responsible poultry production.

References

1. Saeed M, Afzal Z, Afzal F, Khan RU, Elnesr SS, Alagawany M et al. 2023. Use of postbiotic as growth promoter in poultry industry: A review of current knowledge and future prospects. Food Sci Anim Resour. 43(6): 1111-1127.
2. Abd El-Hack ME, El-Saadony MT, Salem HM, El-Tahan AM, Soliman MM, Youssef GBA et al. 2022. Alternatives to antibiotics for organic poultry production: types, modes of action and impacts on bird's health and production. Poult Sci. 101: 101696.
3. Salminen S, Collado MC, Endo A, Hill C, Lebeer S, Quigley EMM et al. 2021. The International Scientific Association for Probiotics and Prebiotics consensus statement on the definition and scope of postbiotics. Nat Rev Gastroenterol Hepatol. 18: 649-667.
4. Soren S, Mandal GP, Samanta I, Hansda RN. 2023. Saccharomyces cerevisiae based postbiotics: Assessment of their effects on the health and productive performance of poultry. Pharma Innovation J. SP-12(8): 572-575.
5. Soren S, Mandal GP, Mondal S, Pradhan S, Mukherjee J, Banerjee D et al. 2024. Efficacy of Saccharomyces cerevisiae fermentation product and probiotic supplementation on growth performance, gut microflora and immunity of broiler chickens. Animals. 14: 866.
6. Soren S, Ghosh R, Mandal GP, Mandal S, Samanta I. 2025. Impact of postbiotic produced from Lactobacillus rhamnosus NCDC 298 as a replacement for antibiotics on the growth performance, gut health and immune response in broiler chickens. Int J Bio-resource Stress Manag. 16(12): 1-11.
7. Raj V, Soren S, Goswami S, Seikh A, Mandal GP, Mondal S et al. 2026. Effects of dietary supplementation of Lactobacillus-based probiotic and postbiotic on growth performance, carcass traits, blood biochemical profiles and gut health in Rainbow Rooster chickens. Eur J Nutr Food Saf. 18(9): 178-188.
8. Seikh A, Mondal S, Mandal GP, Roy B, Mandal S, Ghosh P et al. 2025. Comparative study of probiotics and postbiotics on growth performance, carcass traits, and blood biochemical profiles in broiler chickens. Int J Vet Sci Anim Husbandry. 10(10): 45-50.
9. Abd El-Ghany WA, Fouad H, Quesnell R, Sakai L. 2022. The effect of a postbiotic produced by stabilized non-viable Lactobacilli on the health, growth performance, immunity, and gut status of colisepticaemic broiler chickens. Trop Anim Health Prod. 54: 286.

Volume: 06 Issue No: 09

PLANT DERIVED VACCINES & INDUSTRIALLY IMPORTANT COMPOUNDS

Article ID: AG-VO6-I09-104

[1]Akshay K, [1]Deiva Prakash V, [1]Keshav Meena, [1]Swapnajit Behera,

[1]Afrin Frank B S and [2]Sivaji M

[1]UG Student, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu 606 753

[2]Teaching Assistant Agricultural Biotechnology, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu 606 753

*Corresponding Author **:** Akshay K

Introduction

Plant biotechnology is one of the fastest-growing branches of science that combines biology with modern genetic engineering techniques to improve plants and produce valuable products. Through transgenic technology, foreign genes are inserted into plant genomes to express desired traits or produce commercially important proteins. Vaccines are among the most effective tools for controlling infectious diseases. However, conventional vaccine production is often expensive, requires sophisticated manufacturing facilities, and depends on continuous cold-chain storage & transportation. These limitations became particularly evident during the COVID-19 pandemic, emphasizing the need for alternative, rapid, & cost-effective vaccine production systems.

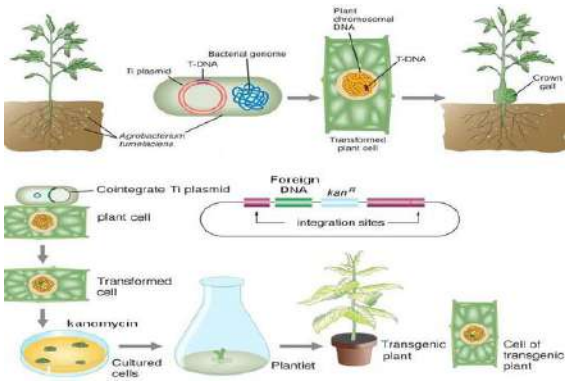


Figure 1. Overview of transgenic technology in plants

Transgenic plants are increasingly being used as green bioreactors for the production of vaccines, antibodies, enzymes, industrial proteins, & pharmaceuticals. Compared with traditional production systems using animal cells or microorganisms, plants offer several advantages, including low production cost, easy scalability reduced risk of contamination with animal pathogens, & environmentally friendly production methods.

Today, several plant species such as tobacco, Nicotiana benthamiana, potato, tomato, maize, rice, lettuce, & banana are being explored for producing vaccines and industrially important compounds. Among these, Nicotiana benthamiana is the most widely used host plant because of its rapid growth, ease of genetic transformation, & ability to produce high levels of recombinant proteins.

Plant-derived vaccines & industrial compounds represent a major advancement in plant molecular farming, where genetically engineered plants function as living biofactories to produce high-value pharmaceutical proteins, therapeutic antibodies, industrial enzymes, & other commercially valuable biomolecules. This innovative technology has the potential to improve global healthcare, support sustainable industrial production, & enhance the availability of affordable medicines, particularly in developing countries.

What is transgenic technology?

Transgenic technology is the process of introducing a foreign gene (transgene) into the genome of a plant using genetic engineering techniques to express a desired trait or produce a valuable product. The inserted DNA is called a transgene, and the resulting genetically modified plant is known as a transgenic plant. The introduced gene is stably integrated into the plant genome and can be inherited by subsequent generations. Transgenic technology has revolutionized modern agriculture and biotechnology by enabling the production of crops with improved agronomic traits and plants capable of producing pharmaceuticals, vaccines, industrial enzymes, and other commercially valuable compounds. It forms the foundation of plant molecular farming, in which plants serve as biological factories for producing high-value biomolecules.

Objectives -

- Improve crop productivity & yield.
- Develop resistance to insects and pests.
- Enhance resistance to diseases caused by bacteria, fungi, & viruses.

- Develop herbicide-tolerant crops for effective weed management.
- Improve tolerance to drought, salinity, heat, & other abiotic stresses.

Enhance nutritional quality (biofortification)

- Produce plant-derived vaccines & therapeutic proteins.
- Produce industrial enzymes & pharmaceuticals.
- Improve shelf life & post-harvest quality of crops.
- Reduce dependence on chemical pesticides and fertilizers.
- Promote sustainable & environmentally friendly agriculture.

Molecular Farming

Molecular farming is the production of high-value pharmaceutical and industrial products in genetically engineered (transgenic) plants using recombinant DNA technology. In this approach, plants act as green biofactories to produce valuable proteins, vaccines, antibodies, enzymes, hormones, and other biologically active compounds.

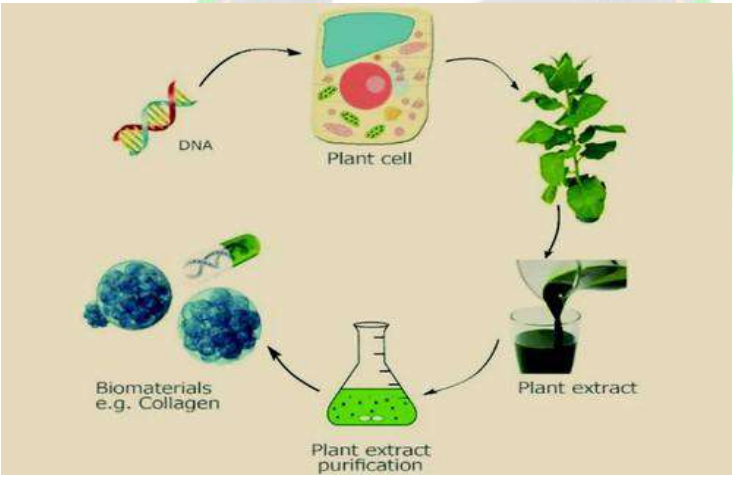


Figure 2 . Production of recombinant biomaterials (e.g., collagen) in transgenic plants through molecular farming.

Unlike conventional production systems that use microorganisms or animal cell cultures, molecular farm environmentally friendly production platforms. The desired gene is introduced into the plant genome, allo during its normal growth and development Principle of Molecular Farming -

Molecular farming is based on the expression of a foreign gene (transgene) in a plant. The inserted gene directs the plant cells to synthesize the desired recombinant protein which is then extracted, purified, and processed for pharmaceutical or industrial applications

Steps Involved in Molecular Farming -

1. Selection of the gene of interest.
2. Isolation & cloning of the desired gene.
3. Construction of a recombinant DNA vector.
4. Transfer of the gene into plant cells using Agrobacterium tumefaciens or a gene gun.
5. Regeneration of transgenic plants through tissue culture.
6. Expression of the recombinant protein.
7. Harvesting of plant tissues.
8. Extraction and purification of the target protein.
9. Processing into commercial pharmaceutical or industrial products.

Plant-derived vaccines & industrially important compounds

Plant-derived vaccines

Plant-derived vaccines are vaccines produced by genetically engineered plants that express antigenic proteins capable of inducing immunity against infectious diseases. These vaccines are developed by introducing genes encoding pathogen-specific antigens into plant cells using recombinant DNA technology. The plants then synthesize these antigenic proteins, which can be purified for vaccine production or, in some cases, administered through edible plant tissues.

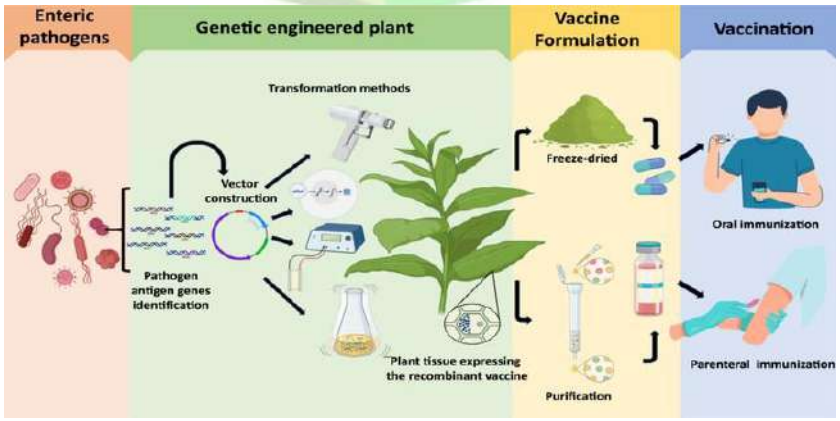


Figure 3. Schematic representation of the production & delivery of plant-derived vaccines using transgenic plants

Plant-derived vaccines have emerged as a promising alternative to conventional vaccines because they are safe, cost-effective, & environmentally friendly. Unlike traditional vaccine production systems that require expensive fermentation facilities & strict cold-chain storage, plants can be cultivated on a large scale with relatively low production costs. This approach gained significant attention during the COVID-19 pandemic, which highlighted the need for rapid & scalable vaccine production technologies. The most commonly used plant for vaccine production is Nicotiana benthamiana, a close relative of tobacco. It is widely preferred because of its rapid growth, ease of genetic transformation, and ability to produce high levels of recombinant proteins. Other plants such as potato, tomato, lettuce, rice, maize, and banana are also being explored, particularly for the development of edible vaccines.

Production of Plant-Derived Vaccines

Plant-derived vaccines are produced by introducing genes encoding pathogen-specific antigens into plant cells using recombinant DNA technology. The transformed plants synthesize the antigenic proteins, which are then purified and formulated into vaccines or, in some cases, administered directly as edible vaccines. Plant-based vaccine production is economical, scalable, and can rapidly respond to emerging infectious diseases. Recent advances in plant molecular farming have enabled vaccine production within a few weeks during disease outbreaks.

Steps include -

1. Identification of Antigen Gene

The first step is to identify and isolate the gene encoding the antigenic protein of the target pathogen (virus, bacterium, or parasite). This antigen should be capable of inducing a protective immune response without causing disease.

2.Gene Cloning

The selected antigen gene is amplified using molecular biology techniques such as PCR and cloned into a suitable cloning vector to obtain multiple copies.

3.Vector Construction

The cloned gene is inserted into a plant expression vector, usually the *Ti plasmid* of *Agrobacterium tumefaciens*. The vector also contains a promoter, terminator, and selectable marker gene for efficient expression in plants.

4.Gene Transfer

The recombinant vector is transferred into plant cells using methods such as:

- *Agrobacterium*-mediated transformation (most common)
- Gene gun (biolistics)
- Electrophoresis
- PEG-mediated transformation

5.Plant Regeneration

The transformed cells are cultured on nutrient media containing plant growth regulators. Through tissue culture techniques, these cells regenerate into complete transgenic plants expressing the foreign gene.

6.Expression of Antigen

The inserted gene is expressed in the plant, resulting in the production of the desired antigenic protein. The antigen accumulates in leaves, fruits, seeds, or tubers depending on the crop used.

7. Harvesting

The plant tissues containing the recombinant antigen are harvested at the appropriate stage of growth to obtain maximum protein yield.

8.Purification

The antigenic protein is extracted and purified using chromatographic & biochemical techniques to obtain a highly pure vaccine antigen suitable for human or veterinary use.

9.Vaccine Formulation

The purified antigen is formulated into a vaccine by adding stabilizers &, when required, adjuvants to enhance the immune response. The vaccine then undergoes quality testing before clinical use.

Table 1. Plant-Derived Vaccines Produced Through Transgenic Technology

Plant Host	Disease Targeted	Antigen Produced	Application / Use
Potato	Hepatitis B	Hepatitis B Surface Antigen (HBsAg)	Protects against Hepatitis B virus infection and liver disease.
Potato	Cholera	Cholera Toxin B Subunit (CT-B)	Prevents cholera caused by *Vibrio cholerae*.
Potato	Norovirus	Capsid Protein (VP1)	Prevents viral gastroenteritis caused by Norovirus.
Tomato	Rabies	Rabies Virus Glycoprotein	Provides immunity against rabies virus infection.
Lettuce	Hepatitis B	Hepatitis B Surface Antigen (HBsAg)	Protects against Hepatitis B virus infection.
Banana	Oral vaccine research	Various recombinant antigens	Experimental edible vaccines for easy oral immunization, especially in children.
Rice	Experimental vaccines	Recombinant antigenic proteins	Used for thermostable vaccine production and long-term storage.
Maize	Experimental vaccines	Recombinant antigenic proteins	Produces recombinant proteins and edible vaccines for human and veterinary use.
	Influenza	Hemagglutinin (HA)	Used for the production of influenza vaccine candidates.

Tobacco (*Nicotiana benthamiana*)	COVID-19	Virus-Like Particles (VLPs)	Used in the production of the Covifenz COVID-19 vaccine.
	Classical Swine Fever	E2 Glycoprotein	Veterinary vaccine used to protect pigs from Classical Swine Fever.
	Porcine Circovirus	Capsid Protein (Virus-Like Particle)	Veterinary vaccine used to prevent Porcine Circovirus disease in pigs.

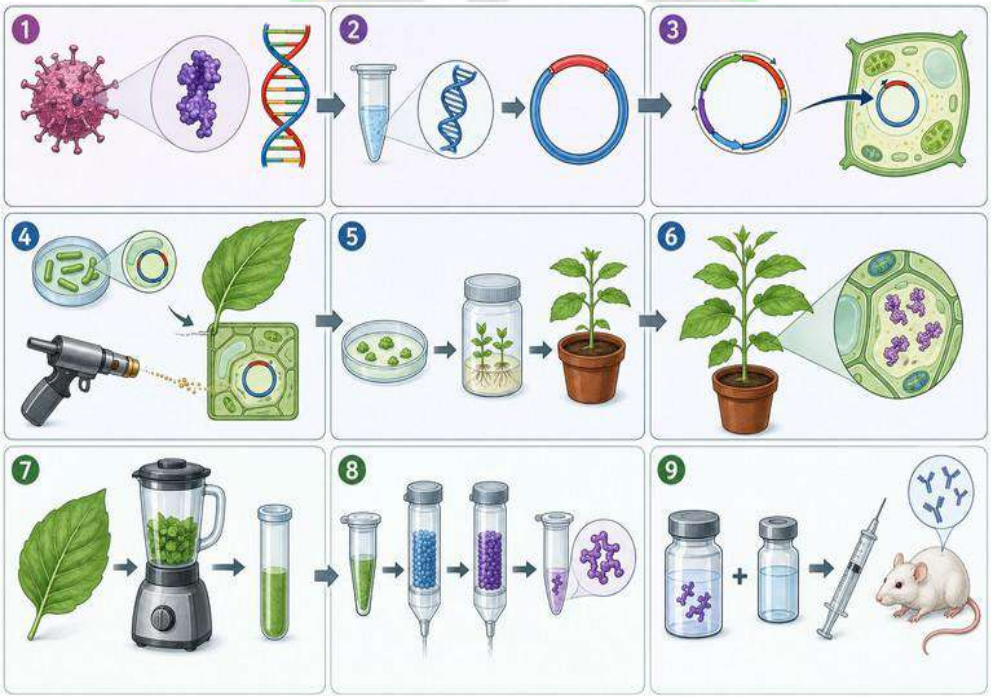


Figure 4. Stepwise production of plant-derived vaccines using transgenic technology

INDUSTRIALLY IMPORTANT COMPOUNDS

Industrially important compounds are valuable biological products produced in transgenic plants for pharmaceutical, agricultural, food, and industrial applications. Through transgenic technology, plants are genetically engineered to synthesize commercially important proteins, enzymes,

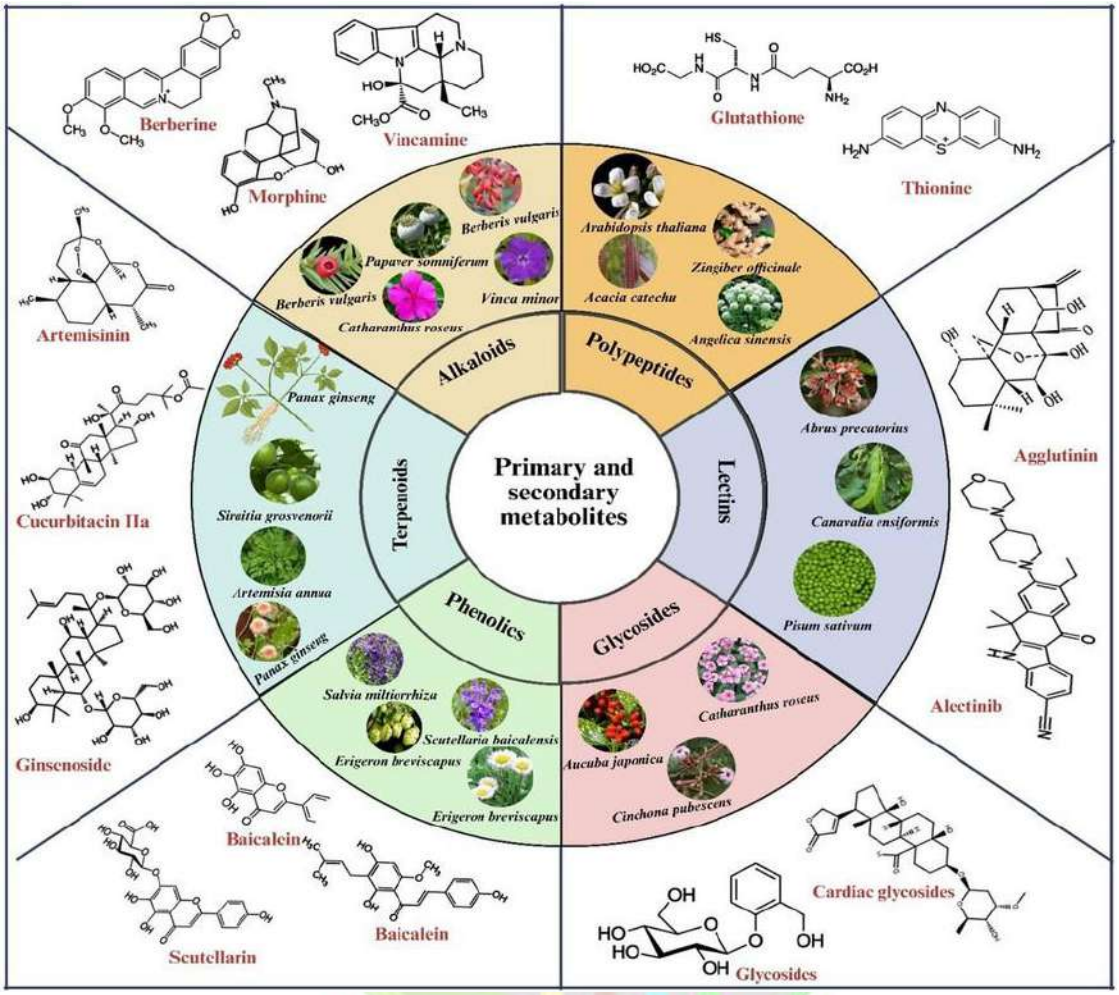


Figure 5. Classification of primary and secondary metabolites produced by plants with representative examples.

metabolites, and biomaterials that are difficult or expensive to produce using conventional methods.

The production of these compounds in plants is known as plant molecular farming. Plants act as green biofactories, producing high-value biomolecules in a safe, economical, and environmentally sustainable manner. Compared with microbial and animal cell culture systems, plant-based production offers advantages such as low production costs, easy scalability, reduced risk of contamination by animal pathogens, and the ability to produce complex proteins with proper folding and post-translational modifications. Industrially important compounds produced in transgenic plants are widely used in medicine, agriculture, food processing, textile industries, paper manufacturing, biofuel production,

biodegradable plastics, cosmetics, and environmental protection.

Major Categories and Their Applications -

1. Pharmaceutical Industry

Industrially important compounds produced in transgenic plants are widely used in the pharmaceutical industry for the production of vaccines, therapeutic proteins, antibodies, and hormones.

Product	**Example**	**Application**
Plant-derived vaccines	Covifenz (COVID-19 vaccine), HERBAVAC CSF Green	Prevention of infectious diseases
Therapeutic proteins	Human insulin, Human serum albumin	Treatment of diabetes and blood disorders
Monoclonal antibodies	ZMapp (anti-Ebola antibody), anti-HER2 antibodies	Cancer therapy and treatment of infectious diseases
Hormones	Human Growth Hormone (hGH)	Treatment of growth hormone deficiency
Blood proteins	Lactoferrin, Human albumin	Infant nutrition and plasma replacement

1. Food Industry

Transgenic plants improve food quality by producing vitamins, nutritional proteins, and food-processing enzymes.

Product	**Example**	**Application**
Vitamin-enriched crops	Golden Rice (Vitamin A)	Prevents Vitamin A deficiency
Food processing enzymes	Amylase	Bread making and starch processing
Food processing enzymes	Chymosin (Rennet)	Cheese production
Nutritional proteins	Lactoferrin	Infant formula and nutritional supplements

1. Agriculture

Industrially important compounds improve crop productivity, animal nutrition, and disease resistance.

Product	Example	Application
Animal feed enzyme	Phytase	Improves phosphorus availability in poultry and livestock feed
Disease-resistant crops	Virus-resistant Papaya	Protection against Papaya Ringspot Virus
Insect-resistant crops	Bt Cotton	Protection against bollworms
Nutritionally improved crops	Golden Rice	Enhanced nutritional quality

2. Industrial Sector

Transgenic plants produce enzymes and biodegradable materials used in various industries.

Product	Example	Application
Paper industry enzyme	Xylanase	Eco-friendly paper bleaching
Textile enzyme	Cellulase	Fabric polishing and stone washing of denim
Biofuel enzyme	Cellulase	Conversion of cellulose into bioethanol
Bioplastics	Polyhydroxybutyrate (PHB)	Manufacture of biodegradable plastic products

3. Environmental Applications

Plant-derived industrial compounds contribute to environmental sustainability & pollution reduction.

Product	Example	Application
Eco-friendly bioplastics	Polyhydroxybutyrate (PHB)	Replaces petroleum-based plastics
Phytoremediation plants	Transgenic Indian mustard	Removal of heavy metals from contaminated soil
Biofuel enzymes	Cellulase	Production of renewable biofuels
Biodegradable materials	Plant-based polymers	Reduces plastic pollution and environmental waste



Figure 6 - Golden Rice genetically engineered to produce provitamin A (β-carotene) for improving nutritional quality.

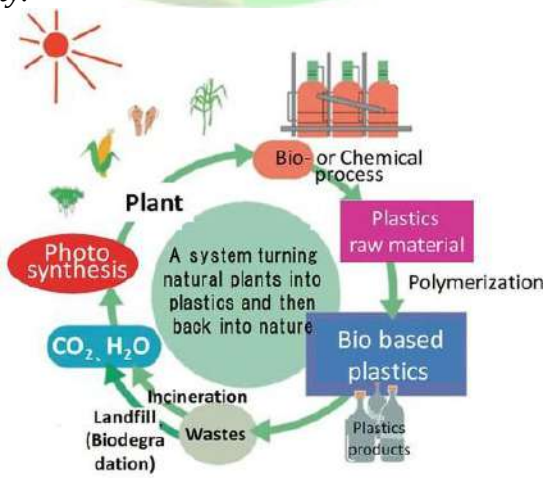


Figure 7. Production of bio-basedbiodegradable plastics from plants through transgenic technology.

Taliglucerase Alfa – A Plant-Derived Therapeutic Protein

Taliglucerase alfa is the world's first FDA-approved recombinant therapeutic protein produced in genetically engineered plant cells. It is used as an enzyme replacement therapy (ERT) for the treatment of Type I Gaucher disease, a rare inherited lysosomal storage disorder. Taliglucerase alfa is produced using genetically modified carrot (*Daucus carota*) cell suspension cultures, making it an important example of molecular farming and transgenic technology in medicine.



Gaucher disease is a rare autosomal recessive genetic disorder caused by a deficiency or absence of the enzyme glucocerebrosidase (β-glucocerebrosidase). This enzyme is responsible for breaking down glucocerebroside, a lipid molecule, within the lysosomes of macrophages. When the enzyme is deficient or non-functional, glucocerebroside accumulates inside the lysosomes, leading to progressive damage in various organs & tissues. As a result, patients develop symptoms such as enlargement of the liver and spleen (hepatosplenomegaly), bone pain, frequent fractures, anaemia, low platelet count (thrombocytopenia), fatigue, & , in severe forms of the disease, neurological complications.

Taliglucerase alfa is a recombinant form of the human enzyme glucocerebrosidase produced in genetically engineered (transgenic) carrot cells using recombinant DNA technology. It is used as an enzyme replacement therapy (ERT) for the treatment of Gaucher disease, a rare genetic disorder caused by the deficiency of glucocerebrosidase. After intravenous administration, the enzyme is taken up by macrophages through mannose receptor-mediated endocytosis and transported to the lysosomes, where it hydrolyses the accumulated glucocerebroside into glucose and ceramide, thereby restoring normal lysosomal function and reducing disease symptoms. Taliglucerase alfa is a landmark achievement in plant biotechnology, as it is the first plant cell-derived therapeutic protein approved by the U.S. Food and Drug Administration (FDA). Its successful development demonstrates the immense potential of plant molecular farming for producing safe, effective, and high-quality

biopharmaceuticals. Compared with conventional mammalian cell culture systems, production in transgenic carrot cells is more economical, reduces the risk of contamination by animal pathogens, minimizes dependence on animal-derived production systems, and enables the large-scale production of recombinant therapeutic proteins for clinical use.

Carrot (Daucus carota) cells are preferred for the production of Taliglucerase alfa because they provide a safe, efficient, and economical platform for producing recombinant therapeutic proteins. Although plants such as tobacco (Nicotiana benthamiana), rice, maize, potato, and lettuce are widely used in molecular farming for producing vaccines and other recombinant proteins, carrot cells offer several unique advantages for enzyme production. Unlike whole plants, carrot cells can be grown as sterile suspension cultures in controlled bioreactors, ensuring consistent quality and year-round production without being affected by environmental conditions.

Compared with bacterial and yeast expression systems, carrot cells perform proper protein folding and produce human-compatible glycosylation patterns, which are essential for the biological activity and efficient uptake of Taliglucerase alfa by macrophages. In addition, carrot cells are free from animal pathogens such as viruses and prions, reducing the risk of contamination associated with mammalian cell cultures. They also provide high protein stability, are easier to scale up commercially, and require lower production costs than mammalian cell culture systems. Furthermore, the use of carrot cell cultures is environmentally friendly and minimizes dependence on animal-derived production systems, making transgenic carrot cells the most suitable host for the commercial production of Taliglucerase alfa.

Production of Taliglucerase Alfa (Commercial Process)

Isolation of Human Glucocerebrosidase Gene

The human glucocerebrosidase (GBA) gene is isolated from human DNA.

↓

Construction of Recombinant Vector

The gene is inserted into a suitable plant expression vector containing:

- Promoter
- Terminator
- Selectable marker gene

↓

Transformation of Carrot Cells

The recombinant vector is introduced into carrot cells using Agrobacterium tumefaciens.

↓

Selection of Transgenic Cells

Successfully transformed carrot cells are selected on selective culture media.

↓

Cell Suspension Culture

Selected transgenic carrot cells are grown in sterile liquid bioreactors to produce large quantities of recombinant enzyme.

↓

Expression of Taliglucerase Alfa

The genetically engineered carrot cells synthesize recombinant glucocerebrosidase enzyme.

↓

Harvesting

The cultured carrot cells are harvested after maximum enzyme production.

↓

Purification

The enzyme is extracted and purified using chromatographic techniques to obtain pharmaceutical-grade Taliglucerase alfa.

↓

Quality Control

The purified enzyme is tested for:

- Purity
- Biological activity
- Safety
- Sterility

Formulation

The purified enzyme is formulated into an injectable medicine and supplied for intravenous infusion.

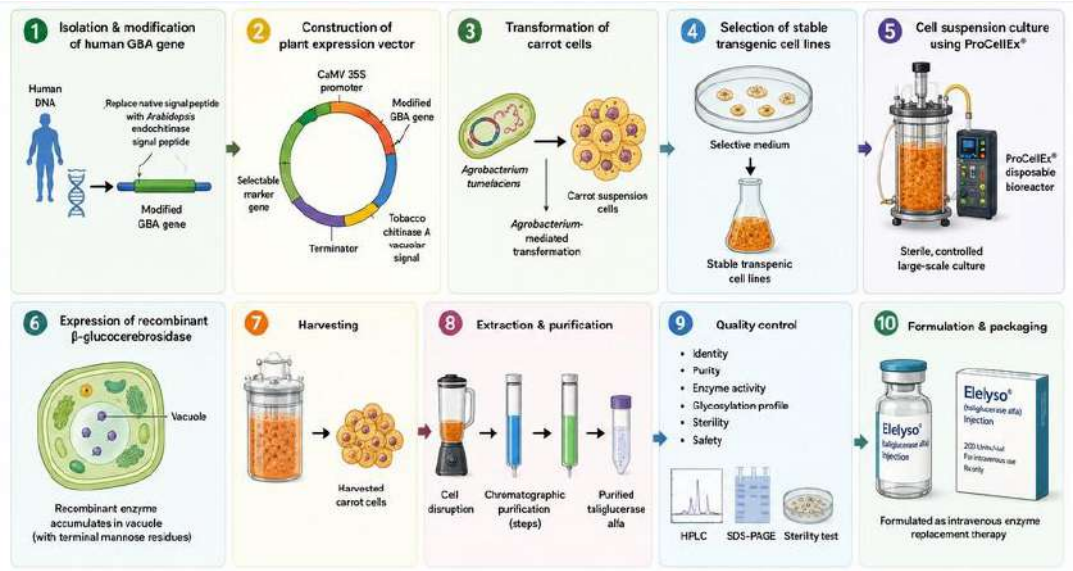


Figure 8. Stepwise production of Taliglucerase alfa (Elelyso®) in transgenic carrot cells using plant molecular farming technology..

Conclusion

Transgenic technology has revolutionized modern plant biotechnology by enabling the production of valuable pharmaceutical & industrial products in plants. Plant-derived vaccines represent a safe, cost-effective, & sustainable alternative to conventional vaccine production, offering advantages such as large-scale production, reduced risk of contamination, & the potential for rapid response during disease outbreaks. Similarly, transgenic plants have become important sources of industrially valuable compounds, including therapeutic proteins, enzymes, antibodies, vitamins, bioplastics, & secondary metabolites. The use of plants as green biofactories through molecular farming has opened new opportunities in medicine, agriculture, food processing, and industrial biotechnology. Although challenges such as regulatory approval, public acceptance of genetically modified crops, & standardization of production remain, continuous advances in genetic engineering, molecular farming, & genome-editing technologies are addressing these limitations.

Overall, plant-derived vaccines & industrially important compounds produced through

transgenic technology have great potential to improve global healthcare, ensure sustainable industrial production, & contribute to future innovations in biotechnology. Continued research & commercialization of these technologies will play a significant role in meeting the growing demand for affordable medicines and high-value biological products worldwide.

REFERENCE -

Hai-Ping Diao, Yong-Feng Guo, Yong Chen, Inhwan Hwang, Shi-Jian Song. Dec 16 2025. Plant-Derived Vaccines: Advances In Delivery Approaches. NATIONAL LIBRARY OF MEDICINE.

B. Vinod Kumar, T. K. Raja, M. R. Wani, S. A. Sheikh, M. A. L, Gowher Nabi, M. M. Azooz, Muhammad Younis, Maryam Sarwat and Parvaiz Ahmad. 23 October, 2013. Transgenic Plants As Green Factories For Vaccine Production. AFRICAN JOURNAL OF BIOTECHNOLOGY.

Julian K -C Ma, Eugenia Barros, Ralph Bock, Paul Christou, Philip J Dale, Philip J Dix, Rainer Fischer, Judith Irwin, Richard Mahoney, Mario Pezzotti, Stefan Schillberg, Penny Sparrow, Eva Stoger, Richard M Twyman. 2005. Molecular Farming For New Drugs & Vaccines. NATIONAL LIBRARY OF MEDICINE

Richa Sao & Parmeshwar Kumar Sahu. 23.12.2019. MOLECULAR FARMING AS AN APPROACH FOR PRODUCTION OF USEFUL METABOLITES. Journal of Plant Development Sciences Vol. 11(12): 697-704. 2019.

Nicolai Kallscheuer, Thomas Classen, Thomas Drepper, Jan Marienhagen. 2019. Production of plant metabolites with applications in the food industry using engineered microorganisms. Current Opinion in Biotechnology 2019, 56:7–17.

Volume: 06 Issue No: 09

BIOSTIMULANTS IN FRUIT PRODUCTION: ENHANCING PLANT PERFORMANCE AND ORCHARD SUSTAINABILITY

Article ID: AG-VO6-I09-105

Harmala Kaur[1] and *Dimpy Raina[2]

[1]M.Sc. Fruit Science, Department of Fruit Science, Punjab Agricultural University, Ludhiana, Punjab, (141004), India

[2]Assistant Professor Fruit science, Department of Fruit Science, Punjab Agricultural University, Ludhiana, Punjab, (141004), India

*Corresponding Author : Dimpy Raina

Abstract

The intensification of fruit production has increased productivity but has also raised concerns related to soil degradation, excessive fertilizer use, abiotic stresses and sustainable fruit production. Bio-stimulants enhance natural physiological and biochemical processes and have emerged as useful tools for sustainable orchard management. This review summarizes major bio-stimulant categories, their mechanisms, applications and limitations in fruit crops. Important groups include humic substances, seaweed extracts, protein hydrolysates, chitosan, botanical extracts, arbuscular mycorrhizal fungi (AMF) and plant growth-promoting rhizobacteria (PGPR). These products can improve root growth, nutrient-use efficiency, stress tolerance, plant growth and fruit quality. Beneficial responses have been reported in kiwifruit, grapevine, pomegranate, apple, strawberry, sweet orange and sweet cherry. However, product variability, cultivar-specific responses, environmental dependence and limited standardization remain major challenges. Future research should focus on product standardization, field validation and precision application for sustainable fruit production.

Keywords: Biostimulants, Fruit crops, Sustainable orchard management, Plant growth promotion, Nutrient-use efficiency, Abiotic stress tolerance and Seaweed extracts

Introduction

Fruit crops are high-value commodities that require stable productivity and consistent quality under increasingly variable environmental conditions. Intensification of production has simultaneously increased concerns related to soil degradation, groundwater contamination from excess fertilizer use, abiotic stress and consumer demand for residue-free produce (Sunitha *et al*. 2022). Bio-stimulants have emerged as an alternative approach because they activate or amplify plant physiological processes rather than functioning primarily as direct nutrient sources (Zhang and Schmidt 2000). Their relevance is particularly high in fruit crops because yield and quality are strongly affected by drought, salinity, temperature extremes and nutritional imbalance (Afonso *et al*. 2022).

The present synthesis follows the progression from the basic concept of bio-stimulation to its principal categories, mechanisms, crop responses, limitations and future applications. The emphasis is on the evidence and quantitative examples reported in the supplied review material.

Definition and basic functions

The term bio-stimulant describes materials that promote plant growth or stimulate plant nutrition processes independently of their nutrient content. EU Regulation 2019/1009 identifies plant bio-stimulants according to their ability to improve nutrient-use efficiency, tolerance to abiotic stress, quality traits or the availability of nutrients in the soil or rhizosphere. Their effects arise through overlapping physiological, biochemical and molecular mechanisms.

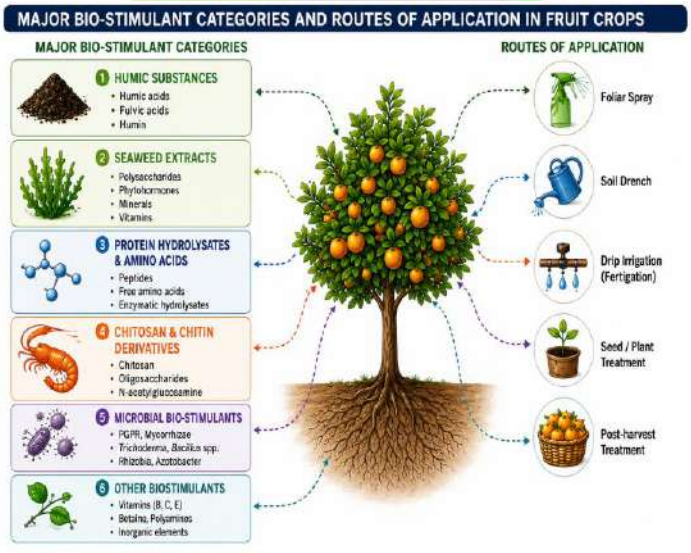


Fig.1 Major bio-stimulant categories and their routes of application in fruit crops.

Major functional responses include enhancement of nutrient-use efficiency through improved root development and nutrient mobilization; improved abiotic-stress tolerance through antioxidant defence, compatible-solute accumulation and stomatal regulation; growth promotion through hormone-like activity; improvement of fruit quality including TSS, firmness, colour and functional compounds; and modification of the rhizosphere through improved soil properties and beneficial microbial interactions (Canellas *et al*. 2015; Tanou *et al*. 2017). Fig.1 demonstarcte the categories of biostimulants and the routes of application

Major categories of bio-stimulants

Humic and Fulvic Acids

Humic substances originate from the decomposition and transformation of organic matter and include humic acids, fulvic acids and humins. Their effects involve both direct plant responses and indirect soil-mediated effects. Reported mechanisms include stimulation of plasma-membrane H^+-ATPase activity, auxin-like promotion of lateral roots, enhancement of nitrogen assimilation and activation of antioxidant systems. Soil effects include improved aggregate stability, cation-exchange capacity, micronutrient chelation and stimulation of beneficial microorganisms (Canellas *et al*. 2015).

In kiwifruit, humic-acid treatment improved root length and plant height, with 'Hayward' showing an approximately 18% increase in root length at 10% concentration. In grapevine, 50 mL L^{-1} humic acid produced the highest reported yield: 3.275 kg $vine^{-1}$ in 'Feteasca Regala' and 2.91 kg $vine^{-1}$ in 'Riesling Italian', representing increases of 31% and 34%, respectively, over the controls. TSS increased from 17.15 to 19.14 °Brix and from 18.95 to 20.97 °Brix, respectively (Dutta *et al*. 2023; Popescu *et al*. 2018).

Seaweed Extracts

Seaweed extracts, particularly those derived from brown algae such as *Ascophyllum nodosum* and *Ecklonia maxima*, contain polysaccharides, betaines, amino acids, minerals and phytohormone-like compounds. Their reported functions include stimulation of cell division and root development, delayed senescence, activation of defence signalling and improved tolerance to osmotic stress. Laminarin can act as an elicitor, while betaines contribute to protection of membranes and enzymes under stress (Spann and Little 2011; Rajendra *et al*. 2024).

In pomegranate, seaweed-based bio-stimulant treatment reduced fruit cracking while improving fruit size and volume. In apple, combined Solubor, Biozyme and triacontanol

produced the highest bloom index (51.65%), fruit set (74.71%), fruit yield (97.75%) and TSS (15.74%), while reducing pre-harvest fruit drop to 11.19% compared with 25.09% in the water-treated control (Abubakar *et al*. 2013; Zubair *et al*. 2017).

Protein Hydrolysates

Protein hydrolysates contain free amino acids, short peptides and polypeptides generated from plant or animal protein sources. Their activity is associated with improved nitrogen use, stress metabolism and signalling. Proline, glutamate and GABA contribute to stress responses, while short peptides can activate signalling pathways associated with defence and growth (Paskovic *et al*. 2024).

In organic strawberry production, alfalfa protein hydrolysate produced fruit firmness of 0.73 kg cm^{-2}, TSS of 7.07 °Brix and colour chroma of 34.51. A mixed amino-acid treatment produced the highest TSS of 8.70 °Brix, whereas chitosan produced the highest fruit firmness of 0.84 kg cm^{-2} among the evaluated treatments (Soppelsa *et al*. 2019).

Chitosan and Botanical Extracts

Chitosan is produced by deacetylation of chitin and can act as a signalling elicitor. Recognition of chitosan oligomers can initiate calcium-mediated signalling, reactive oxygen species and nitric oxide production, leading to activation of stress-responsive and secondary-metabolism pathways (Rahman *et al*. 2018; Tanou *et al*. 2017). Reported effects in fruit crops include improved root growth, mineral uptake, disease resistance, fruit quality and post-harvest shelf life.

Botanical bio-stimulants contain plant-derived secondary metabolites such as phenolics, terpenoids, alkaloids and phytohormone-like compounds. Moringa leaf extract is particularly notable because of its zeatin, vitamins, amino acids, minerals and antioxidant compounds. In Washington Navel orange, combined soil-applied humic acid with foliar seaweed and moringa extracts produced 100.78 kg fruit $tree^{-1}$ (38.70 t ha^{-1}), compared with 69.88 kg $tree^{-1}$ (26.82 t ha^{-1}) in the zero-amendment control, a 44% increase. Fruit drop decreased from 83.0% to 68.56% and fruit number increased from 248 to 307 fruit $tree^{-1}$ (Almutairi *et al*. 2024).

Arbuscular Mycorrhizal Fungi and PGPR

AMF form symbiotic associations with roots and extend the effective absorptive area through extraradical hyphae. Their principal benefits include improved phosphorus and nitrogen acquisition, enhanced drought tolerance and improved root hydraulic function. PGPR include

beneficial bacteria from genera such as Bacillus, Pseudomonas and Azospirillum. They can promote growth through nitrogen fixation, phosphate solubilization, siderophore production, phytohormone synthesis and ACC-deaminase activity, while also suppressing soil-borne pathogens. In sweet cherry, combined Pseudomonas BA-8 and Bacillus OSU-142 produced the highest yield efficiency (0.112 kg cm^{-2} trunk cross-sectional area) and shoot length reached 19.05 cm compared with 14.70 cm in the untreated control (Afonso *et al*. 2022).

Table 1. Major Bio-stimulants, their examples and primary targets :

Category	Examples	Primary target
Humic & fulvic acids	Leonardite, vermicompost extracts	Root growth, nutrient chelation
Seaweed extracts	Ascophyllum nodosum, Ecklonia maxima	Stress tolerance, growth regulation
Protein hydrolysa-tes	Alfalfa, collagen, vegetable sources	Amino-acid supply, NUE, chlorophyll
Chitosans	Crustacean-shell derivatives	Systemic resistance, nutrient uptake
Botanical extracts	Moringa, neem, aloe vera	Hormone-like effects, antioxidants
AMF	Glomus spp., Rhizophagus irregularis	P, N and micronutrient uptake
PGPR	Bacillus, Pseudomonas, Azospirillum	N fixation, P solubilization, IAA

Integrated Bio-stimulant Management

The evidence indicates that combined bio-stimulant programmes can target complementary physiological processes simultaneously. Humic substances can improve the rhizosphere and nutrient availability, seaweed and botanical extracts can influence growth and stress signalling, protein hydrolysates can support nitrogen metabolism, chitosan can prime defence responses, and AMF or PGPR can enhance nutrient acquisition and biological activity. Such combinations may therefore provide broader benefits than single-product applications when the products, concentrations and timings are appropriately matched to crop requirements.

Challenges and Limitations

Despite positive responses, commercial adoption is constrained by product compositional variability, mechanistic complexity, crop- and cultivar-specific responses, stress-dependent efficacy and regulatory inconsistency. Biological raw materials can vary with season, geographical origin, harvesting conditions and processing method, making standardization difficult. The same product and application rate may also produce different responses among cultivars, rootstocks, soils and climates. Therefore, multi-location field validation and stronger mechanistic studies are needed before broad recommendations are made.

Conclusion

Bio-stimulants represent a shift from conventional input-oriented orchard management toward biologically responsive crop production. Evidence summarized in the supplied review shows that humic and fulvic acids, seaweed extracts, protein hydrolysates, chitosan, botanical extracts, AMF and PGPR can improve growth, yield, fruit quality and stress resilience when appropriately formulated and applied. The strongest future opportunity lies in integrated programmes that combine complementary mechanisms while using precision application and omics-based approaches to improve consistency. Product standardization, crop-specific validation and harmonized regulation remain essential for reliable adoption.

References

Abubakar, A., Bhat, M. Y., Mir, M. R., Banday, S. A. and Dar, W. A. (2013). Effect of biostimulants on fruit cracking, fruit size, fruit weight and fruit volume of pomegranate cv. Kandhari Kabuli. *Asian J. Plant Sci. Res. 3*:1–10.

Afonso, S., Arrobas, M. and Rodrigues, M. A. (2022). Soil and plant analyses to diagnose nutrient limitations in cherry orchards and guide fertilization programs in sustainable agriculture. *J. Soil Sci. Plant Nutr. 22*:3227–44.

Almutairi, K. F., Sas-Paszt, L. and Mosa, W. F. A. (2024). The role of some biostimulants in improving the productivity of orange. *Sustainability 16*(16):7131.

Canellas, L. P., *et al*. (2015). Humic and fulvic acids as biostimulants in horticulture. *Sci. Hortic. 196*:15–27.

Dutta, P., Chaulya, B., Chakraborty, A. and Bera, S. (2023). Differential response of kiwifruit cultivars to bio-stimulant solution treatments: Effects on root length and plant height. *Sci. Hortic. 316*:111966.

European Parliament and Council (2019). Regulation (EU) 2019/1009 laying down rules on the making available on the market of EU fertilising products. Off. J. Eur. Union L170:1–114.

Paskovic, I., Popovic, L., Pongrac, P., Polic Paskovic, M., Kos, T., Jovanov, P. and Franic, M. (2024). Protein hydrolysates—production, effects on plant metabolism, and use in agriculture. *Horticulturae 10*(10):1041.

Popescu, G. C., Popescu, M. and Cana, A. (2018). Effect of humic acid foliar application on yield and quality of grapevine (Vitis vinifera L. cv. Feteasca Regala and cv. Riesling Italian) in Stefanesti, Romania. *Sci. Hortic. 226*:1–8.

Rahman, M., Mukta, J. A., Sabir, A. A., Gupta, D. R., Mohi-Ud-Din, M., Hasanuzzaman, M., Miah, M. G., Rahman, M. and Islam, M. T. (2018). Chitosan biopolymer promotes yield and stimulates accumulation of antioxidants in strawberry fruit. *PLoS ONE 13*:1–14.

Rajendra, B. N., Bhaskar, J., Naidu, S. A., Sethunath, K., Billal, M., Manohar, A., Raghavan, M. and Patra, S. (2024). Exploring seaweed extracts: Novel benefits for fruit crops growth. *J. Adv. Biol. Biotechnol. 27*:1102–19.

Soppelsa, S., Kelderer, M., Casera, C., Bassi, M., Brischetto, P. and Andreotti, C. (2019). Foliar applications of biostimulants promote growth, yield and fruit quality of strawberry plants in production system. *Agronomy 9*:483.

Spann, T. M. and Little, H. A. (2011). Applications of a commercial extract of the brown seaweed Ascophyllum nodosum increases drought tolerance of container-grown 'Hamlin' sweet orange trees. *HortScience 46*:577–82.

Sunitha, C., Madhavi, M., Sandhyarani, M., Jasmitha, M., Srinivasulu, B. and Pradeep Kumar, P. (2022). Role of biostimulants in fruit crops: A review. *Pharma Innov. J. 11*:2041–48.

Tanou, G., Ziogas, V. and Molassiotis, A. (2017). Foliar nutrition, biostimulants and prime-like dynamics in fruit tree physiology: New insights on an old topic. *Front. Plant Sci. 8*:75.

Zhang, X. and Schmidt, R. E. (2000). Hormone-containing products' impact on antioxidant status of tall fescue and creeping bentgrass subjected to drought. *Crop Sci. 40*:1344–49.

Zubair, M., Khan, A. S. and Ahmad, T. (2017). Effect of biostimulants on improving floral characteristics, yield and quality of apple cv. Red Delicious. *J. Hortic. Sci. 12*:188–94.

Volume: 06 Issue No: 09

"CLASS – E" WATER AS AN ALTERNATIVE IRRIGATION SOURCE UNDER INCREASING WATER SCARCITY: A CASE PERSPECTIVE FROM POLLUTED RIVER THENPENNAI

Article ID: AG-VO6-I09-106

Codisha. D

3rd Year, B.Sc. (Hons) Agriculture, Institute of Agriculture, TNAU,

Kumulur – 621712, Trichy, Tamil Nadu, India

Abstract

Increasing water scarcity, population growth, urbanization and competition for freshwater resources are creating a need for alternative sources for irrigation. Reuse of wastewater and polluted surface water has therefore received increasing attention, particularly in water stressed conditions. In India, surface- water bodies are classified according to their designated best use, with Class E should not be interpreted as an unconditional indication that the water is suitable for all crops, soils and irrigation practices. In this article let us explore about what is "class- e" water, and how its suitable for agriculture with various quality parameters with an actual example from the polluted river Thenpennai.

Keywords: Class- E water, water scarcity, alternative source, Thenpennai river.

Introduction:

Water reuse in agriculture can provide an important source of irrigation water while simultaneously recovering nutrients contained in wastewater. Wastewater may contain nitrogen, phosphorus, potassium and organic matter that can contribute to crop production. However, it can also contain salts, sodium, chloride, pathogens, heavy metals and other contaminants. Therefore, the agricultural reuse of poor-quality water presents both an opportunity and a potential environmental and public-health challenge. FAO guidance emphasizes that irrigation-water suitability depends not only on the water itself but also on soil properties, climate, crop salt tolerance and management practices.

CPCB CLASSIFICATION FOR CLASS-E WATER:

S.NO	CHARACTERS	TOLERANCE LIMIT
1.	pH value	6.0 – 8.5
2.	EC at 25degree, microsimen, max	2250
3.	SAR, max	26
4.	Boron, mg\l, max	2.0
5.	TDS(inorganic),mg\l, max	2100
6.	Sulphates (as So4),mg\l , max	1000
7.	Chlorides(as Cl), mg\l, max	600
8.	Sodium%, max	60
9.	Alpha emitters, mg\l, max	10^{-9}
10.	Beta emitters, mg\l, max	10^{-8}

SOURCE AND ORIGIN OF CLASS-E WATER:

Water may enter the Class E category because of deterioration in quality caused by natural or anthropogenic activities. Potential sources include:

- Urban wastewater
- Sewage-impacted surface water
- Industrial discharges
- Agricultural drainage
- Urban stormwater
- Mixed domestic and industrial wastewater
- Polluted rivers
- Polluted lakes and drains
- Treated wastewater effluents

The composition of the resulting water depends strongly on its source.

For example, domestic wastewater may contain considerable organic matter and nutrients, whereas industrially influenced water may contain metals or specific chemical contaminants. Agricultural drainage may contain salts, nutrients and agrochemicals.

Consequently, the origin of Class E water must be established before deciding whether it is appropriate for agricultural reuse.

PHYSIOCHEMICAL CHARACTERS RELEVANT TO IRRIGATION:

1.pH:

pH influences nutrient availability, chemical reactions and the mobility of several contaminants. The CPCB Class E criterion is 6.0–8.5.

However, pH should not be interpreted independently. A water source with acceptable pH may still present serious salinity, sodicity, metal or microbial problems.

2. ELECTRICAL CONDUCTIVITY AND TOTAL DISSOLVED SALTS:

FAO irrigation guidelines categorize EC below 0.7 dS/m as having no salinity restriction, 0.7–3.0 dS/m as slight to moderate restriction and values above 3.0 dS/m as severe restriction under the general guideline framework. Therefore, a Class E water sample should be evaluated using actual EC, rather than relying only on the fact that it satisfies the Class E maximum.

3.SODICITY AND SODIUM ABSORPTION RATIO:

The sodium adsorption ratio (SAR) expresses sodium concentration relative to calcium and magnesium: **SAR= Na^{+}/ $(Ca^{2+}+Mg^{2+})^{1/2}$ / 2**

when concentrations are expressed in appropriate milliequivalent units.

High SAR water can promote sodium accumulation on soil exchange sites. Sodium can cause clay dispersion, resulting in reduced infiltration, reduced hydraulic conductivity, surface crusting and poor soil physical condition.

FAO explains that the effect of sodium on soil permeability depends on the relationship between SAR and total dissolved salt concentration; therefore, SAR should not be interpreted independently of EC.

4. SPECIFIC ION TOXICITY:

Some ions can become toxic to crops when present at sufficiently high concentrations. Important ions include:

Sodium:

Can cause toxicity when absorbed by plants, particularly under certain irrigation conditions.

Chloride:

High chloride concentrations can cause leaf injury and toxicity, particularly where sprinkler irrigation wets foliage.

Boron:

Boron is an essential micronutrient at low concentrations but becomes toxic above crop-specific thresholds.

A CASE STUDY FROM THENPENNAI RIVER:

Sewage discharge with from Bengaluru is the reason for foaming at Kelavarapalli Dam in Hosur and the increased growth of 'water hyacinth' in the KRP Dam, said Collector C Dinesh Kumar. Studies conducted between April 2025 and March 2026 revealed that Kelavarapalli Dam had high amounts of ammonia, nitrogen, phosphates, fecal matter and coliform bacteria. As a result, the KRP Dam has also been affected by increased water hyacinth growth."

This result shows that the water is regarded unfit for drinking purposes and according to CPCB, this water is put under "CLASS- E".

ACTUAL REPORT OF WATER SAMPLE FROM NGT TESTING:

PARAMETERS	MEAN VALUE IN PPM	HIGHEST PERMITTED VALUE (WHO)	UNIT WEIGHTAGE	Wi*Qi
pH	8.8	8.5	0.1176	12.173
EC	1719	600	0.0016	0.4584
TDS	1197	500	0.002	4.788
TH	374	500	0.002	0.1496
DO	5.5	6	0.166	0.1833
BOD	14.2	10	0.1	14.2
COD	35.4	10	0.1	35.4
Ca	119	100	0.01	1.19
Mg	45	150	0.006	0.198
Cl	241	250	0.004	0.3856
NO3	24	50	0.02	0.96
PO4	0.3	10	0.1	0.3

The above report shows that the river water parameter has more amount of substance than the recommended parameters. To use this type of water under water stress conditions following methods are followed before releasing into field.

Step 1: Comprehensive water-quality assessment

Before using Thenpennai/Class E water for irrigation, water should be analysed for:

Physical parameters

- colour,
- odour,
- turbidity,
- total suspended solids.

Chemical parameters

- pH,
- EC,
- TDS,
- Na,
- Ca,
- Mg,
- Cl,
- SO_4,
- HCO_3,
- B,

Irrigation indices

- SAR,
- RSC,
- sodium percentage,

Pollution indicators

- BOD,
- COD,
- dissolved oxygen.

Microbiological parameters

- total coliforms,
- fecal coliforms/E. coli,
- relevant pathogens.

Potential toxic contaminants

- heavy metals,
- emerging contaminants where justified.

This produces a much more complete picture than relying on Class E classification alone

Step 3: Blending with better-quality water

Where technically and economically feasible, lower-quality water can sometimes be blended with better-quality water.

For example:

Class E water + better-quality freshwater

↓

Reduced concentration of problematic constituents

↓

Improved irrigation-water quality

The actual mixing ratio must be determined through water-quality calculations and field requirements rather than assuming a fixed dilution ratio.

Step 4: Appropriate crop selection

Not every crop has the same tolerance to salinity, sodium or specific ions.

Therefore, crop selection should consider:

- salt tolerance,
- sensitivity to sodium/chloride/boron,
- edible portion,
- irrigation method,
- duration of exposure,
- intended market use.

This becomes especially important when microbial contamination is present.

Step 5: Irrigation-method selection

The irrigation method determines how contaminated water interacts with the soil, plant and farm workers.

Step 6: Soil management

Where salinity or sodicity is the primary concern, soil management becomes essential.

Possible practices include:

- adequate drainage,
- controlled leaching,
- gypsum application where sodicity is established,
- organic-matter management,
- selection of salt-tolerant crops,
- proper irrigation scheduling.

The goal is to prevent the gradual deterioration of soil properties.

Step 7: Continuous monitoring

The safety of agricultural reuse cannot be established through a single water sample.

A better system is:

Water monitoring
↓
Soil monitoring
↓
Crop monitoring
↓
Food-safety monitoring where necessary
↓
Adjustment of irrigation practices

This is particularly important for a river whose pollution load can change with rainfall, sewage discharge and industrial activity.

Conclusion

The combination of increasing rainfall variability, irrigation-water demand and pollution of surface-water resources presents a complex challenge for Tamil Nadu agriculture. The Thenpennai River illustrates this complexity particularly well because the river remains an

important water resource while simultaneously receiving significant pollution loads. Class E classification provides an important regulatory indication that water can have irrigation as a designated use. However, Class E should not be interpreted as a universal guarantee of agricultural safety. The actual suitability of the water depends on salinity, sodicity, specific-ion toxicity, microbial contamination, other pollutants, soil characteristics, crop tolerance and irrigation management.

References

1.https://www.who.int/publications/i/item/9241546832?utm_source=chatgpt.com

2.https://cpcb.gov.in/wqm/Designated_Best_Use_Water_Quality_Criteria.pdf?utm_source=chatgpt.com

3. https://www.newindianexpress.com/states/tamil-nadu/2026/Jul/04/bengaluru-sewage-causing-foaming-at-kelavarapalli-dam-says-krishnagiri-collector?utm_source=chatgpt.com

4. https://timesofindia.indiatimes.com/city/chennai/ngt-tells-ktaka-stop-untreated-sewage-from-entering-thenpennai/articleshow/123621235.cms?utm_source=chatgpt.com

Volume: 06 Issue No: 09

CAN WE GROW MORE FOOD WITH LESS WATER?: THE RACE FOR WATER-SMART CROPS

Article ID: AG-VO6-I09-107

Saurav Raj[1] and Devendra Kumar Payasi[2*]

[1]Department of Genetics and Plant Breeding, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, R.A.K College of Agriculture, Sehore, Madhya Pradesh 466001, India.

[2]Senior Scientist & Incharge, ICAR-AICRP on Soybean, Department of Genetics and Plant Breeding, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, R.A.K. College of Agriculture, Madhya Pradesh 466001, India

*Corresponding Author: Devendra Kumar Payasi

Introduction

In late July, a soybean farmer in central India walks his field before sunrise, pressing a thumb into the topsoil the way his father taught him. The monsoon is ten days late, and the crop needs water now, at flowering, or the pods will never fill properly. He can run the pump longer and draw down a borewell that sinks a little deeper every year, or he can wait and hope. Multiply that decision by hundreds of millions of farms worldwide, and you have today's central agricultural dilemma: the world must grow substantially more food in the coming decades even as the water available to grow it becomes less predictable and more contested.

Agriculture already claims most of the fresh water humans withdraw from rivers, lakes and aquifers, and simply digging more wells or building more canals runs into a hard ceiling (Bulle et al. 2026). So a different question has moved to the center of crop science: instead of only asking how to deliver more water to a field, can we redesign the crop itself to produce more food from every drop it receives?

What Does “Water-Smart” Actually Mean?

Using less water can simply mean a smaller, hungrier crop. Using water more efficiently changes how and when water is delivered. But producing more yield per unit of water the goal breeders are chasing means changing the plant so each liter it absorbs contributes more to the

harvest. This is water-use efficiency, or WUE: the biomass or yield a plant produces relative to the water it loses through transpiration, mostly via the stomata on its leaves (Bulle et al. 2026). The same stomata that let water escape are also the doors through which carbon dioxide enters for photosynthesis, so a plant cannot simply shut them to save water without also starving itself of carbon. The whole chain — uptake, transport, transpiration, photosynthesis, biomass, yield has to be tuned together, not squeezed at one valve (Deng et al. 2026).

The Roots of the Solution Are Underground

Roots form the first component of a water-smart plant, determining how effectively soil moisture can be accessed at different depths (Fig. 1). A system that grows deep can tap moisture stored well below where a shallow-rooted crop ever reaches (Kaur et al. 2026). Breeders now describe root angle, lateral branching, root-hair density and plasticity a root's ability to change its growth pattern as soil moisture shifts in almost as much detail as canopy traits. But deeper is not automatically better: roots are metabolically expensive, and a plant that invests heavily below ground can yield less in a wetter year than a shallower-rooted sibling that put more resources into grain (Hafeez et al. 2024; Franco-Navarro et al. 2025). The goal is the right root architecture for a given climate and soil, not simply the deepest one possible.

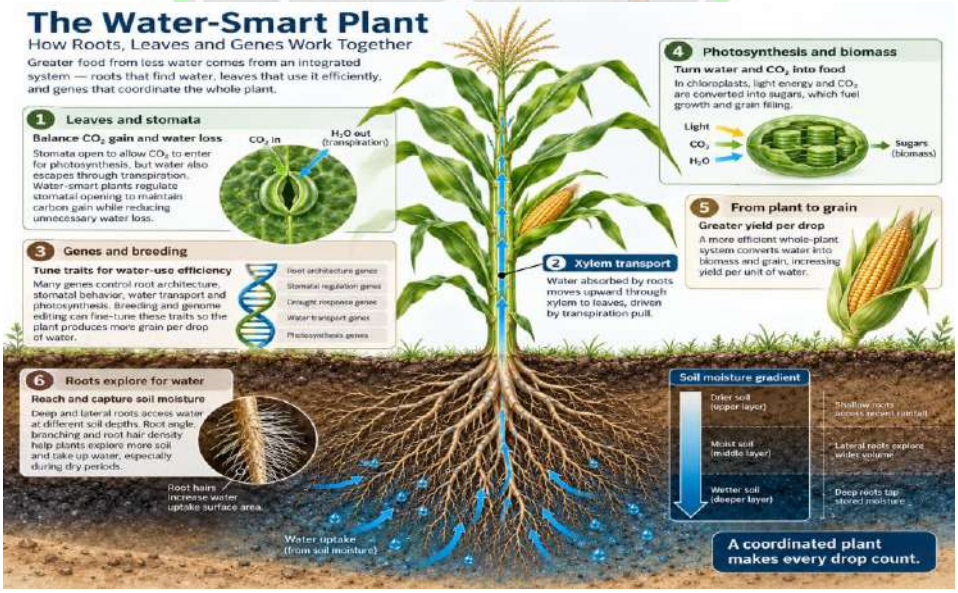


Fig. 1. The water-smart plant: integration of root architecture, water transport, stomatal regulation and genetic control to improve water-use efficiency and sustain crop yield under variable water availability.

Source: Author's illustration, based on concepts discussed by Kaur et al. (2026), Chamarthi et al. (2024), Chen et al. (2024) and Deng et al. (2026).

Breeding Plants to "Do More With Less"

Traditional breeding grows thousands of plants under stress and crosses the survivors slow, and not well suited to a trait shaped by dozens of genes. Modern programs now layer genomic tools on top: marker-assisted selection uses a DNA marker linked to a trait; genome-wide association studies, or GWAS, scan whole genomes across many varieties for statistical links to a trait; and genomic selection uses genome-wide markers to predict a plant's likely field performance without pinning the result on any single gene (Escamilla et al. 2025). A 2024 soybean study illustrates the payoff: researchers grew 205 lines across seven site-year-treatment combinations and measured a carbon-isotope signature ($^{13}C/^{12}C$) that tracks lifetime water-use efficiency. Genome-wide mapping linked more than ninety genomic regions to that signature, and genomic prediction models built from those markers could estimate an untested line's water-use efficiency from its DNA alone, though accuracy varied by environment (Chamarthi et al. 2024). Similar genomic strategies are now speeding up water-use-efficiency breeding in wheat (Hafeez et al. 2024).

Can CRISPR Help Crops Use Water More Wisely?

Genome editing tools such as CRISPR/Cas9 make a precise, targeted change to DNA a plant already carries, rather than waiting generations for a desired gene combination to emerge from crosses. Researchers have used this to probe genes controlling stomatal density, root branching, drought signaling and water transport in maize, for instance, an edit that lowers ethylene sensitivity has helped sustain yield when drought strikes during flowering (Chen et al. 2024; Haider et al. 2026). But CRISPR is not a shortcut around biology: water-use efficiency is polygenic, so editing one gene rarely delivers a complete fix and can carry unintended trade-offs, an edit that works in one genetic background may do little in another, and a result from a growth chamber still has to survive field validation and regulatory review before it reaches a farmer's field (Franco-Navarro et al. 2025).

The Plant Is Only Half the Story

Even a superbly bred, water-efficient genotype cannot solve the problem alone if it is flood-irrigated with no attention to soil health or timing. Drip and precision irrigation, soil-moisture sensors, mulching, conservation tillage and deliberate deficit irrigation all help stretch every drop further. Layered on top is a fast-growing digital layer: satellite and drone-based remote sensing can flag water stress before it is visible to the eye (Cudjoe et al. 2026), and AI-

guided, variable-rate irrigation systems report meaningful water savings while maintaining or improving yield compared with fixed-schedule irrigation (Yaqoob et al. 2026). Genetics, agronomy and digital technology work best as one integrated system rather than three competing solutions (Deng et al. 2026).

Can We Really Grow More With Less?

The honest answer is: not through any single breakthrough. Water-smart agriculture will be chipped away at through better genetics, better roots, healthier soils, smarter irrigation and digital tools that let all of the above talk to each other in something close to real time. What has changed in just the past few years is the realism and reach of that ambition breeders can now read the genetic basis of water-use efficiency with a precision that did not exist a decade ago, and farmers can watch soil moisture update on a phone screen. The next major advance in agricultural water conservation may not come from a new dam or a more efficient sprinkler at all. It may come from the crop standing in the field quietly doing more with every drop it is given.

How Water-Smart Crops Can Be Built

Table 1. *Key breeding and technology targets for building more water-efficient crops, with representative sources*

Target	What scientists are improving	Technology	Potential benefit	Reference
Root architecture	Deeper, better-angled roots that reach residual soil moisture	Root phenotyping and GWAS (Kaur et al. 2026)	Access to water later in the season	Kaur et al. (2026)
Stomatal regulation	Balance between CO_2 uptake and water loss	Editing of stomatal density/aperture genes (Chen et al. 2024)	Less water lost without cutting photosynthesis	Chen et al. (2024)
Water-use efficiency	Carbon fixed per unit of water transpired	Isotope screening + genomic prediction (Chamarthi et al. 2024)	Faster ID of efficient genotypes	Chamarthi et al. (2024)
Yield stability	Consistent performance	Multi-environment	Fewer year-to-	Escamilla et

Target	What scientists are improving	Technology	Potential benefit	Reference
	across wet and dry years	genomic selection (Escamilla et al. 2025)	year yield swings	al. (2025)
Precision phenotyping	Measuring root and canopy traits at scale	UAV/sensor-based phenotyping (Cudjoe et al. 2026)	Faster, higher-volume selection	Cudjoe et al. (2026)
Gene editing	Fine-tuning single water-related genes	CRISPR/Cas9 (Haider et al. 2026)	Targeted change without long backcrossing	Haider et al. (2026)

.

References

Bulle, M., Vaikuntapu, P. R., and Subudhi, P. K. 2026. Editorial: water use efficiency (WUE): enhancing crop resilience using agronomic and genetic strategies under abiotic stress conditions. Front. Plant Sci. 17:1951554.

Chamarthi, S. K., Purcell, L. C., Fritschi, F. B., Ray, J. D., Smith, J. R., Kaler, A. S., King, C. A., and Gillman, J. D. 2024. Association mapping for water use efficiency in soybean identifies previously reported and novel loci and permits genomic prediction. Front. Plant Sci. 15:1486736.

Chen, F., Chen, L., Yan, Z., Xu, J., Feng, L., He, N., Guo, M., Zhao, J., Chen, Z., Chen, H., Yao, G., and Liu, C. 2024. Recent advances of CRISPR-based genome editing for enhancing staple crops. Front. Plant Sci. 15:1478398.

Cudjoe, D. K., Sun, Y., Li, S., and Guo, W. 2026. Spatial and temporal scales in plant phenotyping for crop water stress assessment: a review. Plant Phenome J. 9:e70073.

Deng, X., Shi, L., Kang, S., Liu, Z., Xu, H., Wang, Y., Huo, Z., Li, Y., Li, J., and Wang, T. 2026. Breaking biological and abiotic limits of agricultural water use efficiency – a review. Agric. Water Manage. 333:110583.

Escamilla, D. M., Li, D., Negus, K. L., Kappelmann, K. L., Kusmec, A., Vanous, A. E., Schnable, P. S., Li, X., and Yu, J. 2025. Genomic selection: essence, applications, and prospects. Plant Genome 18:e70053.

Franco-Navarro, J. D., Padilla, Y. G., Álvarez, S., Calatayud, Á., Colmenero-Flores, J. M., Gómez-Bellot, M. J., Hernández, J. A., Martínez-Alcalá, I., Penella, C., Pérez-Pérez, J. G., Sánchez-Blanco, M. J., Tasa, M., and Acosta-Motos, J. R. 2025. Advancements in water-saving strategies and crop adaptation to drought: a comprehensive review. Physiol. Plant. 177:e70332.

Hafeez, A., Ali, S., Javed, M. A., Iqbal, R., Khan, M. N., Çığ, F., El Sabagh, A., Abujamel, T., Harakeh, S., Ercisli, S., and Ali, B. 2024. Breeding for water-use efficiency in wheat: progress, challenges and prospects. Mol. Biol. Rep. 51:429.

Haider, S., Singh, A. P., Panthi, B., Sindhu, S. R., Safa, N. T., Malik, S., and Rahimi, M. 2026. Advances in CRISPR/Cas9 genome editing for crop improvement and global food security. Curr. Plant Biol. 46:100593.

Kaur, V., Yadav, S. K., Yadav, B., Madaan, S., Kheralia, M., and Chinnusamy, V. 2026. Root system architecture and drought adaptation: emerging tools and genetic insights. Front. Plant Sci. 17:1753086.

Yaqoob, N., Farooque, A. A., Shah, S. H. H., Abbas, F., and Hassan, M. 2026. Variable rate irrigation through digital agriculture for sustainable water management: a meta review on current challenges and future directions. Water Resour. Manage. 40(6):237.

Volume: 06 Issue No: 09

COMPARATIVE PERSPECTIVES ON SPIDER AND SILKWORM SILK: BIOSYNTHESIS, STRUCTURE, PROPERTIES AND FUTURE PROSPECTS

Article ID: AG-VO6-I09-108

***Sharmela S, Sivaranjani S, Sithiya S, Priyadharshini S, Murthy S, Jayaraman R, Suresh S and Sridharan S**

Department of Sericulture, Forest College and Research Institute, TNAU,

Mettupalayam, Tamil Nadu, India

*Corresponding Author : Sharmela S

Abstract

Silkworm silk and spider silk are structurally related fibrous proteins that differ sharply in mechanical performance, production biology, and commercial tractability. This article draws on recent comparative literature to examine their biosynthesis, hierarchical protein architecture, and mechanical properties, and reviews efforts to engineer silkworms that spin spider-silk-like fibers. Spider dragline silk combines high tensile strength with exceptional extensibility, giving it a toughness that unmodified silkworm silk does not match; yet, the territorial, cannibalistic, and low-yield nature of spiders has kept large-scale spider farming commercially unworkable, even as Bombyx mori sericulture has scaled globally for five thousand years. Multipathway genetic and biofabrication strategies — transgenic silkworm platforms, recombinant spidroin expression, and hybrid electrospinning — are now converging on ways to reproduce spider-silk-like performance from silkworm-based production. This article surveys the comparative biosynthesis and mechanical basis of both silks, outlines engineering approaches reported in the literature, and discusses biomedical, textile, and drug-delivery applications alongside the practical barriers that remain.

Introduction

Two animals separated by roughly 400 million years of evolution have independently solved the same engineering problem: how to turn a liquid protein into a solid fiber stronger, weight for weight, than steel, without heat, pressure, or toxic solvents. The mulberry silkworm,

Bombyx mori, was tamed approximately 5, 000 years ago and became the backbone of a textile industry that clothes and employs millions. The orb-weaving spider has resisted every attempt at domestication and remains something we can only borrow from in milligram quantities.

Spider dragline silk, thread for thread, out-temper Kevlar. Silkworm silk is what stands between a pupa and the outside world for two to three weeks, and what has clothed emperors for longer than most of written history. Understanding why these two chemically similar fibers behave so differently is now less an academic curiosity than a live engineering question because the most promising route to spider silk at scale runs directly through the silkworm.

Production Biology: One Line versus Many

A silkworm makes silk the way a factory runs a single, very long production line. Silk is synthesized in a pair of labial glands occupying nearly a third of the caterpillar's body by the fifth instar. Fibroin, the structural silk protein, is manufactured in the posterior gland and passes into a wider middle section where sericin, a gummy glue protein, is added as an outer coat. It is then drawn through a narrowing anterior duct and out through a single spinneret, emerging as one continuous filament of 800–1500 m in length. One gland, one recipe, one fiber, spun once in a lifetime.

A spider runs something closer to a specialized workshop with several production lines feeding a shared exit. An orb-weaver may carry up to seven distinct silk gland types, each producing chemically distinct silk tuned to a specific job and drawable independently throughout its life. The major ampullate gland spins tough, high-strength dragline silk for the web's frame and lifeline; the flagelliform gland produces the capture spiral, engineered for extreme stretch; minor ampullate silk provides temporary scaffolding; aggregate glands coat the spiral in sticky glue; and tubuliform glands, in females only, spin the egg-sac silk. The silkworm's gland has been bred for over a hundred generations for a uniform, reelable, high-yield fiber; the spider's glands have been shaped by natural selection for mechanical specialization. Both are remarkable feats of natural chemical engineering, simply optimized for different jobs.

Molecular Architecture and Mechanical Performance

Chemically, silkworm fibroin and spider spidroins belong to the same broad family of structural proteins and share the same underlying trick: repetitive, glycine- and alanine-rich motifs fold under the shear and pH changes of the spinning duct into small, ordered β-sheet nanocrystals embedded in a looser amorphous matrix. Spider dragline spidroins (MaSp1 and

MaSp2) carry more proline in their amorphous regions, introducing backbone kinks that allow the matrix to act like a molecular spring, storing and dissipating energy as the fiber stretches. Silkworm fibroin's amorphous region is more regular and less proline-rich, giving a stiffer, less extensible but more easily standardized fiber — useful when the goal is identical thread reeled from tens of thousands of cocoons at once. Both fibers are, in effect, liquid-crystal precursors that self-assemble into solid protein fibers at room temperature and near-neutral pH, a manufacturing feat with no true industrial equivalent.

Material	Tensile strength (MPa)	Extensibility (%)	Toughness (MJ/m³)	Density (g/cm³)
Spider dragline silk (N. clavipes)	1,100	30	160	1.3
Silkworm cocoon silk (B. mori)	550	19	70	1.3
Kevlar 49 (aramid fibre)	3,600	3.5	50	1.44
High-tensile steel wire	1,500	2	6	7.8

The trade-offs become concrete when set against synthetic benchmarks. Kevlar and high-tensile steel both beat the silks on raw tensile strength, but toughness — the energy a fiber absorbs before failing — tells a different story, and on that measure, spider dragline silk stands apart (Table 1).

Table 1. Representative literature values; figures vary with species, spinning speed, humidity, and diet.

Both silks are roughly a fifth as dense as steel; on a strength-per-weight basis, they already outperform most metals; on a toughness-per-weight basis, spider dragline silk is frequently cited as outperforming steel by more than an order of magnitude — light enough to wear, tough enough to stop a projectile, and grown at room temperature from nothing more exotic than protein and water (Gu et al., 2020).

The Domestication Barrier and the Transgenic Workaround

If spider silk is this good, why has it not replaced silkworm silk, nylon, or Kevlar? The answer is behavioral, not chemical. Spiders are territorial and often cannibalistic; therefore,

housing them at farming density reliably shrinks the population within a week. Individual yield is tiny — a few hundred meters of usable dragline silk per spider, against the kilometer-plus a silkworm spins per cocoon — and quality shifts with diet, hydration, temperature, and stress in ways that are hard to standardize. A 2009 Madagascar project hand-collected silk from roughly one million golden orb-weavers, over several years and at enormous cost, to weave a single museum-piece cape — proving spider silk can be woven, but also that spider farming does not scale, a conclusion recent feasibility reviews continue to reach (Guessous et al., 2024).

The workaround is elegant in concept: keep the silkworm's five-thousand-year head start on domestication and reeling infrastructure and give it the spider's genetic recipe. Researchers isolate or synthesize a dragline spidroin gene (commonly MaSp1 or MaSp2, or a shortened synthetic version) and insert it into the silkworm genome using the piggyBac transposon system under a silk-gland-specific promoter, so that the posterior gland co-spins both proteins into one composite fiber. Groups at Notre Dame helped pioneer the piggyBac method, and Kraig Biocraft Laboratories was among the first to commercialize transgenic *"spider silkworms,"* marketed as Dragon Silk and Monster Silk. The resulting fibroin–spidroin composite is not pure spider silk, but reported toughness gains over ordinary silkworm silk have been several times higher in some published works, while retaining reelability and the existing supply chain — a convergence that a recent multipathway review argues can push silkworm-derived fiber into the high-strength, super-toughness bracket long associated with native spider silk (Wang et al., 2025).

Applications, Challenges, and Convergence

Biocompatible and biodegradable composite silk is a candidate for surgical sutures and for tendon, ligament, and nerve scaffolds that must bear load while cells remodel them into living tissue (M., 2024). Functionalized silk hybrids have been explored for controlled and targeted drug delivery (Kiseleva & Krivoshapkin, 2020; Kumari et al., 2026), and electrospun nanofiber mats for wound dressings and filtration membranes (Belbéoch et al., 2021). Lighter, more flexible alternatives to aramid fibers have been discussed for protective textiles, and the combination of low weight with high energy absorption suits ropes, cords, and technical fabrics; because both parent proteins are biodegradable, the composite has also been proposed for sustainable packaging and technical non-wovens.

None of this is close to displacing conventional sericulture. Transgenic lines have historically shown reduced fitness — lower egg viability, slower growth, and more fragile

cocoons — and maintaining the inserted gene across generations is a real husbandry challenge. The silkworm duct evolved for fibroin and sericin at a particular concentration, pH, and shear rate, and spidroin does not always behave the same way inside it, so composite fibers often fall short of native spider properties even when the gene is expressed well. Scale-up from laboratory milligrams to farm-level kilograms remains a bottleneck, and because this is genetically modified livestock, regulatory approval and grower acceptance add complexity unrelated to protein chemistry.

Against this backdrop, the comparison stops being a simple contest and becomes two evolutionary answers to the same materials science problem, and a growing effort to combine the best of both. The silkworm gave sericulture a fiber that could be farmed, reeled, and traded at civilization scale; the spider, still unfarmable, keeps handing over design notes anyway — one gene, one gland, one thread at a time.

Conclusion

Spider silk and silkworm silk remain close relatives at the molecular level, both built from repetitive, glycine-rich structural proteins that self-assemble into β-sheet-reinforced fibers under mild, aqueous spinning conditions. What separates them is biology and behavior rather than chemistry: the silkworm's single gland, once-in-a-lifetime spin has been shaped by five thousand years of domestication into an industrially reliable process, while the spider's multi-gland, on-demand repertoire delivers superior toughness never reproduced at farm scale. The transgenic and biofabrication strategies reviewed here — spidroin gene insertion, recombinant expression, hybrid electrospinning, and multipathway engineering — represent converging attempts to close that gap without abandoning sericulture's existing infrastructure. For a field already built around the silkworm's biology, this comparison points to a practical opportunity: composite or bio-inspired silks that borrow the spider's mechanical performance while keeping the silkworm's farmability may, over the next decade, become a genuine extension of conventional silk production rather than a separate industry.

References

1. Belbéoch, C., Lejeune, J., Vroman, P., & Salaün, F. (2021). Silkworm and spider silk electrospinning: a review. Environmental Chemistry Letters, 19(2), 1737–1763.

2. Branković, M., Zivic, F., Grujovic, N., Stojadinovic, I., Milenkovic, S., & Kotorcevic, N. (2024). Review of spider silk applications in biomedical and tissue engineering. Biomimetics, 9(3), 169.
3. Guessous, G., Blake, L., Bui, A., Woo, Y., & Manzanarez, G. (2024). Disentangling the web: an interdisciplinary review on the potential and feasibility of spider silk bioproduction. ACS Biomaterials Science & Engineering, 10(9), 5412.
4. Gu, Y., Yu, L., Mou, J., Wu, D., Zhou, P., & Xu, M. (2020). Mechanical properties and application analysis of spider silk bionic material. e-Polymers, 20(1), 443–457.
5. Kiseleva, A. P., Krivoshapkin, P. V., & Krivoshapkina, E. F. (2020). Recent advances in development of functional spider silk-based hybrid materials. Frontiers in Chemistry, 8, 554.
6. Kumari, J., Chopra, S., Bharati, S., Bhatia, A., Kanwal, A., & Kanwar, N. (2026). Harnessing the potential of spider silk proteins as emerging biomaterials for drug delivery: classification, comparative evaluation and future perspectives. Drug Development and Industrial Pharmacy, (just-accepted), 1–24.
7. Wang, M., Du, Z., Tong, A., Zhang, Y., Luo, Y., Shi, Z., ... & Chen, F. (2025). Silkworm silk can become a high-strength and super-toughness spider-silk-like fiber: Multipathway engineering strategies and applications. Small Structures, 6(7), 2400639.

Volume: 06 Issue No: 09

ENZYMATIC DEFENSE MECHANISMS IN PLANT BIOTIC STRESS TOLERANCE

Article ID: AG-VO6-I09-109

[1]Durga Prasad T S, [1]Gayathri K B, [1]Afrin Frank B S, [1]Deiva Prakash V, [1]Swapnajit Behera and [2] Sivaji M

[1]UG Student, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu 606 753

[2]Teaching Assistant Agricultural Biotechnology, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu 606 753

Corresponding Author: Durga Prasad T S

Introduction

Biotic stress is a major limiting factor in global agricultural productivity, in the quality of crops, and with regard to food security. Different from abiotic stresses—such as drought, extreme temperatures, or salinity—biotic stress results from interactions with living organisms, such as fungal, bacterial, and viral pathogens, plant-parasitic nematodes, herbivorous insects, and parasitic weeds. Since plants are sessile they cannot avoid these threats; instead they have developed a multi-layered innate immune system which makes use of structural, chemical, and inducible defenses to detect and neutralize potential invaders.A key part of this defense system is the quick activation of enzymes which are involved in defense. These proteins constitute an integrated biochemical network that functions over a number of fronts:

Structural reinforcement: bringing about reactions that reinforce cell walls so that they can resist mechanical penetration and enzymatic degradation.

Direct antagonism involves breaking down the structural components of fungal cell walls and insect exoskeletons in order to stop the development of pathogens.

The biosynthesis of secondary metabolites involves driving the phenylpropanoid and flavonoid pathways in order to produce antimicrobial phytoalexins, lignin, and suberin.

The maintenance of ROS homeostasis: ensuring that the dynamics of these molecules are regulated so that they can function as defence signals without causing damage to their own tissue.

Signaling the activation: producing key defensive hormones such as jasmonic acid in order to enhance the plant's systemic resistance.

It is essential for modern agricultural science to understand these enzymatic mechanisms. By working out these pathways, researchers are able to identify biomarkers for resistance, breed hardy crop varieties, design effective biocontrol strategies, and cut down on dependence on synthetic chemical pesticides.

The Role Of Enzymes In Tolerance To Biotic Stress

Defence by plants against biotic invaders is based on a rapid and closely regulated series of biochemical reactions; when the plant cells recognise pathogen- or damage-associated molecular patterns (PAMPs/DAMPs) they cause a influx of calcium and an oxidative burst, which in turn sets off the subsequent enzymatic reactions.

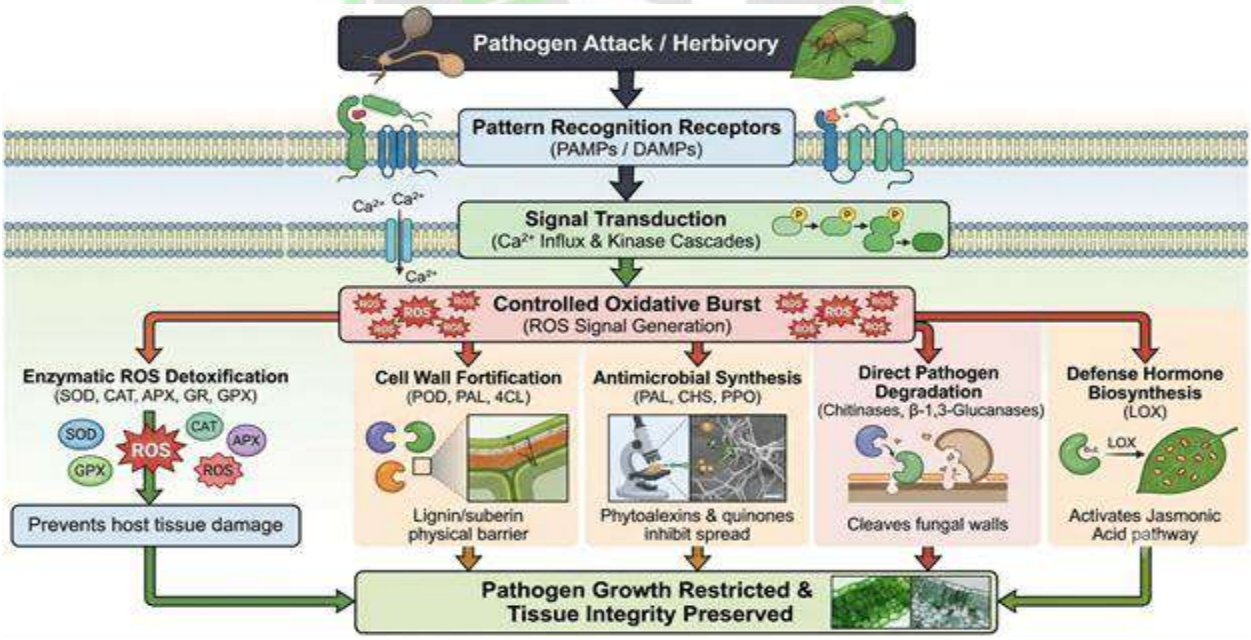


Figure 1. Series of biochemical reactions

Key Physiological Roles

• The generation and signaling of ROS: When there is a controlled accumulation of ROS ($O_2^{\bullet -}$, H_2O_2) it functions as a secondary messenger to activate defense genes and cause the cell wall to become cross-linked.

• The ROS detoxification process is carried out by enzymes such as superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), glutathione reductase (GR), and glutathione peroxidase (GPX), which stop oxidative damage to the host's lipids, proteins, and DNA.

• The cell walls are made stronger through the action of peroxidase (POD), phenylalanine ammonia-lyase (PAL), and 4-coumarate-CoA ligase (4CL), these enzymes promoting the deposition of lignin and suberin so as to make the cell walls more resistant to both mechanical and enzymatic attacks.

• The production of antimicrobial substances involves enzymes acting in the phenylpropanoid and flavonoid pathways, leading to the synthesis of phenolics, flavonoids, and phytoalexins, which in turn disrupt the membranes of pathogens and inhibit germination.

• The structural polysaccharides in fungal cell walls and insect exoskeletons are broken down by hydrolytic enzymes such as chitinases and β-1,3-glucanases, causing the cells to lyse.

• Hormonal defence activation: the lipoxygenase (LOX) starts the biosynthesis of oxylipins, leading to the production of jasmonic acid (JA) in order to activate systemic defences against chewing insects and necrotrophic pathogens.

• Membrane Lipid Protection: Antioxidant enzymes break down lipid hydroperoxides. This helps keep organelle structure and membrane permeability steady during oxidative stress.

• Host-produced polygalacturonase-inhibiting proteins (PGIPs) bind to and neutralise the enzymes that degrade the fungal cell wall.

• The hypersensitive response (HR) involves defence enzymes causing localized and programmed cell death at the sites of infection in order to isolate the biotrophic pathogens and deprive them of nutrients.

• The integration of systemic resistance involves the combined action of these enzymes transforming local recognition of pathogens into long-lasting systemic acquired resistance (SAR) or induced systemic resistance (ISR).

Major Enzymes Involved In Mitigating Biotic Stress

1 Peroxidase (POD)

Peroxidases (EC 1.11.1.7) are heme-containing enzymes that reduce hydrogen peroxide (H_2O_2) to water by oxidizing various organic and inorganic substrates:

$$H_2O_2 + AH_2 \xrightarrow{(POD)} 2\,H_2O + A$$

- **Primary Functions:** Polymerizes cinnamyl alcohols into lignin, cross-links structural proteins (such as hydroxyproline-rich glycoproteins) within cell walls, regulates local H_2O_2 concentrations, and oxidizes phenolics into antimicrobial polymers.
- **Defense Mechanism:** Utilizing H_2O_2 from the oxidative burst, POD rapidly hardens host cell walls around infection sites, preventing physical penetration by fungal appressoria and slowing toxin diffusion.
- **Agricultural Value:** High baseline or inducible POD activity serves as a reliable biomarker for selecting disease-resistant crop germplasm.

2 Polyphenol Oxidase (PPO)

Polyphenol oxidases (EC 1.10.3.1) are copper-containing enzymes that catalyze the O_2-dependent oxidation of o-diphenols into electrophilic o-quinones:

o-Diphenol + O_2 ⟶(PPO)⟶ o-Quinone + H_2O

- **Primary Functions:** Converts phenolics into reactive quinones, forms protective brown barriers around damaged tissues, and cross-links proteins to lower their digestibility for herbivores.
- **Defense Mechanism:** PPO is compartmentalized in plastids, while its phenolic substrates reside in vacuoles. Tissue damage caused by pests or necrotrophs breaks down this barrier, allowing PPO to convert phenolics into quinones that bind and deactivate viral, fungal, or insect enzymes.
- **Agricultural Value:** Elevated PPO activity correlates with increased resistance to foliar pests and necrotrophic fungi.

3 Phenylalanine Ammonia-Lyase (PAL)

PAL (EC 4.3.1.24) catalyzes the deamination of L-phenylalanine to trans-cinnamic acid, marking the entry point into the phenylpropanoid pathway:

L-Phenylalanine ⟶(PAL)⟶ trans-Cinnamic acid + NH_3

- **Primary Functions:** Controls carbon flow into secondary metabolism, providing precursors for lignin, suberin, salicylic acid, and flavonoids.
- **Defense Mechanism:** PAL expression rises quickly upon pathogen recognition. The resulting trans-cinnamic acid feeds downstream pathways that synthesize antimicrobial compounds and strengthen cell walls.

- **Agricultural Value:** PAL activity serves as a core biochemical indicator of plant immune readiness and is a key target for chemical elicitors.

4 Chitinase

Chitinases (EC 3.2.1.14) are Pathogenesis-Related (PR) proteins that hydrolyze β-1,4-linkages in chitin:

$$(GlcNAc)_n + H_2O \xrightarrow{(Chitinase)} (GlcNAc)_{n-x} + (GlcNAc)_x$$

- **Primary Functions:** Degrades chitin in fungal cell walls and insect exoskeletons; generates chitin oligomers that act as immune-triggering elicitors.
- **Defense Mechanism:** Because chitin is absent in plant tissues, chitinases specifically target invading fungal hyphae, causing tip swelling and lysis while releasing fragments that amplify host immune signaling.
- **Agricultural Value:** Expression of recombinant chitinase genes enhances resistance against major fungal pathogens like Rhizoctonia solani and Botrytis cinerea.

5 β-1,3-Glucanase

β-1,3-Glucanases (EC 3.2.1.39; PR-2 family) hydrolyze β-1,3-D-glucosidic linkages in fungal cell wall glucans.

- **Primary Functions:** Degrades structural wall glucans, inhibits hyphal growth and spore germination, and releases elicitor fragments that stimulate defense pathways.
- **Defense Mechanism:** Accumulating in apoplastic spaces during infection, these enzymes weaken fungal cell walls, acting synergistically with chitinases to induce osmotic lysis.
- **Agricultural Value:** Co-expressing β-1,3-glucanase and chitinase offers broad-spectrum protection against fungal pathogens like Fusarium and Pyricularia.

6 Superoxide Dismutase (SOD)

Superoxide dismutase (EC 1.15.1.1) catalyzes the dismutation of superoxide radicals ($O_2^{\bullet -}$) into hydrogen peroxide (H_2O_2) and oxygen (O_2):

$$2\ O_2^{\bullet -} + 2\ H^+ \xrightarrow{(SOD)} H_2O_2 + O_2$$

Isozymes include Cu/Zn-SOD (cytosol/chloroplasts), Mn-SOD (mitochondria), and Fe-SOD (chloroplasts).

- **Primary Functions:** Neutralizes $O_2^{\bullet -}$ radicals generated during the oxidative burst, converting them into H_2O_2 for downstream signaling and detoxification.

- **Defense Mechanism:** Prevents excessive $O_2^{\bullet -}$ accumulation from causing non-specific cell necrosis while generating H_2O_2 to trigger defense gene expression.
- **Agricultural Value:** High SOD induction helps plants handle combined biotic and secondary oxidative stresses.

7 Catalase (CAT)

Catalase (EC 1.11.1.6) is a peroxisomal enzyme that directly decomposes H_2O_2 into water and molecular oxygen without requiring an electron donor:

$2\ H_2O_2$ ⟶(CAT)⟶ $2\ H_2O + O_2$

- **Primary Functions:** High-capacity removal of excess H_2O_2, preventing oxidative damage during high photorespiratory or stress flux.
- **Defense Mechanism:** Fine-tunes cellular H_2O_2 levels to prevent the formation of highly toxic hydroxyl radicals ($OH^{\bullet}$) via Fenton reactions, protecting healthy tissues surrounding infection sites.
- **Agricultural Value:** Stable CAT activity limits unorganized tissue necrosis during necrotrophic pathogen attacks.

8 Ascorbate Peroxidase (APX)

Ascorbate peroxidase (EC 1.11.1.11), a core component of the ascorbate-glutathione (AsA-GSH) cycle, reduces H_2O_2 using ascorbate as an electron donor:

H_2O_2 + 2 Ascorbate ⟶(APX)⟶ $2\ H_2O$ + 2 Monodehydroascorbate

- **Primary Functions:** Scavenges H_2O_2 with high affinity in chloroplasts, mitochondria, and cytosol; protects photosynthetic machinery.
- **Defense Mechanism:** APX maintains low baseline H_2O_2 concentrations in organelles where catalase is absent, protecting photosynthetic complexes during infection.
- **Agricultural Value:** Overexpressing APX protects photosynthetic output during systemic bacterial or viral infections.

9 Glutathione Reductase (GR)

Glutathione reductase (EC 1.8.1.7) uses NADPH to reduce oxidized glutathione disulfide (GSSG) back to reduced glutathione (GSH):

GSSG + NADPH + H^+ ⟶(GR)⟶ 2 GSH + $NADP^+$

- **Primary Functions:** Maintains a high GSH/GSSG ratio, regenerates ascorbate cycle antioxidants, and protects protein thiols from oxidation.
- **Defense Mechanism:** Sustains the supply of reduced glutathione required by APX and GPX, keeping defense regulatory proteins (like NPR1) in active conformations.
- **Agricultural Value:** Robust GR activity maintains cellular redox homeostasis during prolonged pathogen pressure.

10 Glutathione Peroxidase (GPX)

Glutathione peroxidase (EC 1.11.1.9) reduces H_2O_2 and organic hydroperoxides (such as lipid peroxides) using GSH or thioredoxin:

ROOH + 2 GSH ⟶(GPX)⟶ ROH + GSSG + H_2O

- **Primary Functions:** Neutralizes lipid hydroperoxides and halts lipid peroxidation cascades within cellular membranes.
- **Defense Mechanism:** Protects host cell membrane integrity from ROS-mediated degradation during pathogen colonization.
- **Agricultural Value:** Prevents rapid cell membrane breakdown, preserving structural stability under high disease pressure.

11 Lipoxygenase (LOX)

Lipoxygenases (EC 1.13.11.12) catalyze the oxygenation of polyunsaturated fatty acids containing a 1,4-pentadiene structure:

Linolenic acid + O_2 ⟶(LOX)⟶ 13-Hydroperoctadecatrienoic acid (13-HPOT)

- **Primary Functions:** Initiates oxylipin synthesis, yielding jasmonic acid (JA) and green leaf volatiles (GLVs) that modulate defense signaling and deter pests.
- **Defense Mechanism:** Mechanical damage caused by herbivory frees linolenic acid from host membranes. LOX oxidizes this substrate to initiate JA synthesis, turning on genes for proteinase inhibitors and repellent volatiles.
- **Agricultural Value:** Crucial for induced resistance against chewing insects and necrotrophic pathogens; serves as a primary target for biological pest management.

12 Polygalacturonase-Inhibiting Proteins (PGIPs)

PGIPs are cell-wall-localized leucine-rich repeat (LRR) proteins that inhibit fungal endo-polygalacturonases (PGs).

- **Primary Functions:** Binds fungal pectin-degrading enzymes, protecting plant cell wall pectin matrices.
- **Defense Mechanism:** PGIPs block the active sites of fungal PGs. This slows pectin digestion and preserves longer oligogalacturonide (OG) fragments, which trigger downstream host defenses.
- **Agricultural Value:** Heterologous expression of PGIPs enhances resistance against necrotrophic fungi like Botrytis cinerea and Sclerotinia sclerotiorum.

13 4-Coumarate-CoA Ligase (4CL)

4CL (EC 6.2.1.12) catalyzes the ATP-dependent conversion of hydroxycinnamic acids into active CoA thioesters:

p-Coumaric acid + CoA-SH + ATP ⟶(4CL)⟶ p-Coumaroyl-CoA + AMP + PP_i

- **Primary Functions:** Directs carbon flux toward lignin, suberin, and flavonoid biosynthesis.
- **Defense Mechanism:** Increases pools of p-coumaroyl-CoA and feruloyl-CoA, which are incorporated into structural cell walls to restrict pathogen movement.
- **Agricultural Value:** Essential for strengthening vascular tissues against wilt pathogens and leaf blights.

14 Chalcone Synthase (CHS)

CHS (EC 2.3.1.74) initiates flavonoid biosynthesis by condensing three malonyl-CoA molecules with one p-coumaroyl-CoA:

p-Coumaroyl-CoA + 3 Malonyl-CoA ⟶(CHS)⟶ Naringenin chalcone + 4 CoA-SH + 3 CO_2

- **Primary Functions:** Produces chalcones, which are converted into flavonoids, isoflavonoids, and antimicrobial phytoalexins.
- **Defense Mechanism:** Pathogen infection stimulates CHS expression, leading to higher levels of phytoalexins that disrupt microbial membranes and inhibit spore germination.
- **Agricultural Value:** Regulates phytoalexin accumulation, directly influencing resistance in legumes and cereal crops.

15 Cysteine Proteases

Cysteine proteases (EC 3.4.22.-) are proteolytic enzymes that hydrolyze peptide bonds using a catalytic cysteine-histidine dyad.

- **Primary Functions:** Degrades pest and pathogen proteins, executes programmed cell death (HR), and digests peritrophic membranes in insect guts.
- **Defense Mechanism:** Upon activation, these proteases cleave microbial virulence factors and host proteins needed for localized cell death. Ingested proteases disrupt insect digestive tracts, preventing nutrient uptake.
- **Agricultural Value:** Target genes for enhancing resistance against chewing pests and biotrophic pathogens.

Integrated Mechanism of Defense

The plant immune response relies on tightly orchestrated spatial and temporal interactions across these enzyme groups:

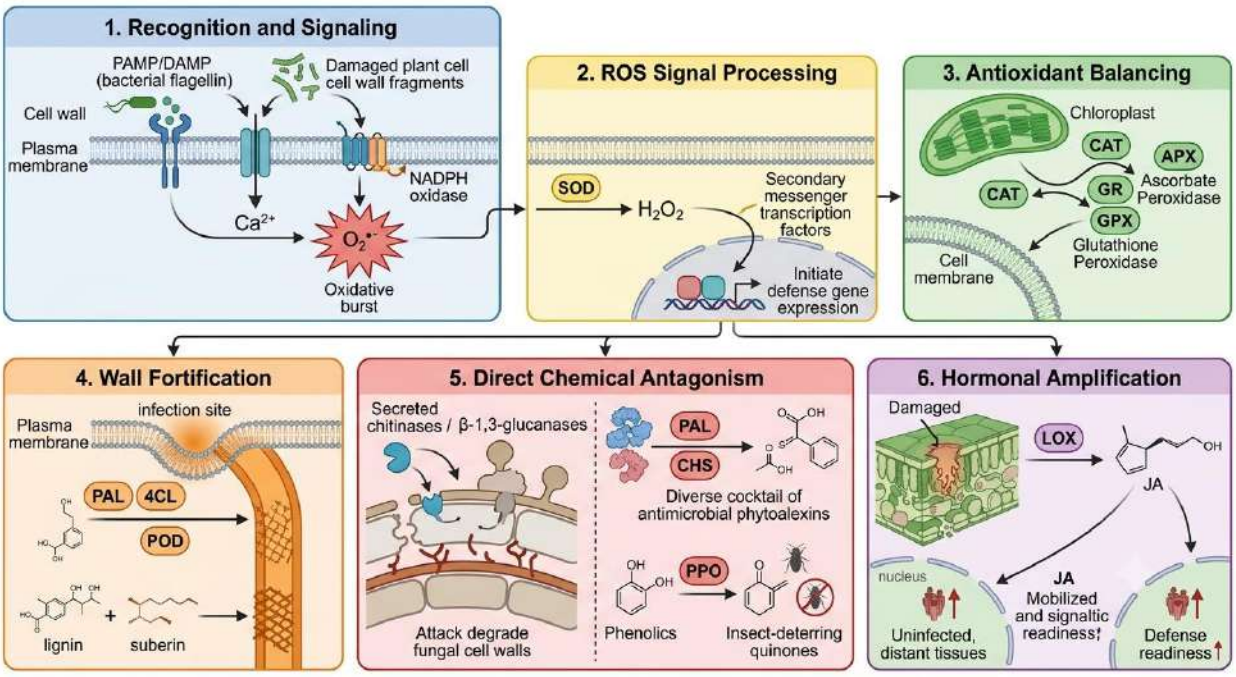


Figure 2. *Integrated Mechanism of Defense*

1. Recognition and Signaling: PAMP/DAMP recognition triggers calcium influxes and an oxidative burst, producing superoxide radicals ($O_2^{\bullet -}$).

2. ROS Signal Processing: SOD converts $O_2^{\bullet -}$ into H_2O_2, which acts as a secondary messenger to activate defense genes.

3. Antioxidant Balancing: CAT, APX, GR, and GPX scavenge excess ROS, protecting host chloroplasts and cell membranes from oxidative destruction.

4. Wall Fortification: PAL, 4CL, and POD synthesize and polymerize lignin and suberin, reinforcing physical cell wall barriers around infection sites.

5. Direct Chemical Antagonism: Secreted chitinases and β-1,3-glucanases degrade fungal cell walls. Simultaneously, CHS and PAL produce antimicrobial phytoalexins, while PPO generates insect-deterring quinones.

6. Hormonal Amplification: Tissue damage prompts LOX to synthesize jasmonic acid, signaling systemic defense readiness in uninfected tissues.

Conclusion

Taken together, enzymes form the biochemical backbone of a plant's ability to sense, withstand, and fight off biotic stress. This defense plays out on several fronts at once. Antioxidant enzymes such as SOD, CAT, APX, GR, and GPX mop up excess reactive oxygen species before they can damage cells, while LOX and cysteine proteases help drive jasmonic acid signaling and trigger targeted cell death where it's needed. At the same time, POD, PAL, CHS, 4CL, and PPO strengthen cell walls through lignification and generate potent antimicrobial phenolic compounds, while chitinases, β-1,3-glucanases, and PGIPs go on the offensive — breaking down pathogen structures directly and disarming the enzymes pathogens use to degrade plant cell walls.

These pathways aren't just interesting biology; they're practical tools for agriculture. Beyond serving as biochemical markers that help breeders identify more resilient crop varieties, defense enzymes can be engineered directly into crops, boosted through biological control agents, or switched on using eco-friendly elicitors. Tapping into these natural defense mechanisms could ease our reliance on synthetic pesticides, paving the way toward more durable disease resistance and more sustainable crop protection.

References

1. Agrios, G. N. (2005). *Plant Pathology* (5th ed.). Elsevier Academic Press.
2. Buchanan, B. B., Gruissem, W., & Jones, R. L. (2015). *Biochemistry and Molecular Biology of Plants* (2nd ed.). Wiley-Blackwell.
3. Taiz, L., Zeiger, E., Møller, I. M., & Murphy, A. (2015). *Plant Physiology and Development* (6th ed.). Sinauer Associates.
4. Dixon, R. A., & Paiva, N. L. (1995). Stress-induced phenylpropanoid metabolism. *The Plant Cell*, 7(7), 1085–1097.

5. Van Loon, L. C., Rep, M., & Pieterse, C. M. J. (2006). Significance of inducible defense-related proteins in infected plants. *Annual Review of Phytopathology*, 44, 135–162.
6. Apel, K., & Hirt, H. (2004). Reactive oxygen species: metabolism, oxidative stress, and signal transduction. *Annual Review of Plant Biology*, 55, 373–399.
7. Durrant, W. E., & Dong, X. (2004). Systemic acquired resistance. *Annual Review of Phytopathology*, 42, 185–209.
8. Howe, G. A., & Jander, G. (2008). Plant immunity to insect herbivores. *Annual Review of Plant Biology*, 59, 41–66.

Volume: 06 Issue No: 09

SEEING IS BELIEVING: FLDS PAVE THE WAY FOR FASTER ADOPTION OF IMPROVED FARM IMPLEMENTS

Article ID: AG-VO6-I09-110

Dr. Sreedevi, M.S.

Associate Professor, AICRP on FIM, Zonal Agricultural Research Station, V.C. Farm, University of Agricultural Sciences, Mandya, Karnataka, India

Introduction

Mechanization is the key to reduce drudgery, save time and labour, and reduce cost of cultivation. Though many improved farm implements and machinery have been developed by SAUs and ICAR institutes and are commercially available, they are not reaching the farming community effectively due to lack of awareness. Keeping this in view, AICRP on Farm Implements and Machinery, ZARS, V.C. Farm, Mandya has taken up Front Line Demonstrations (FLDs) on selected improved equipments in farmers' fields of Mandya district. The FLDs serve as an effective tool for transfer of technology and popularization of new machinery through seeing-is-believing approach. During 2025-26, four improved equipments designed and developed MPKV, Rahuri by were selected based on farmers demand and cropping system of the region namely: Power operated sugarcane sett cutter; Power operated maize dehusker-cum-sheller; Tractor operated sugarcane leaf shredder / detrasher and Tractor operated sugarcane seedling transplanter.

Objectives:

- To conduct demonstrations of improved farm implements in farmers' fields to assess workability, suitability and acceptability.
- To create awareness and encourage farmers to adopt improved implements through demonstrations and trainings.
- To work out the cost economics and field performance to ascertain their practical utility and commercialization.

Materials and Methods: The selected equipments were taken to farmers' fields and demonstrated under actual field conditions. The feedback on performance, labour saving, cost and ease of operation was collected from farmers and stakeholders. A total of 60 demonstrations were conducted covering 5.60 tonnes of material and 12 ha area, benefiting more than 5,664 farmers including farm women.

The details of FLDs conducted are as under:

1. Power Operated Sugarcane Sett Cutter: The machine consists of a 1 hp single phase electric motor, a rotary disc with cutting blades and a feeding chute. The sugarcane stalk is fed manually into the feeding chute. The high speed rotating disc (about 1200-1400 rpm) with sharp blades cuts the cane into uniform 2-budded or 3-budded setts. The length of sett can be adjusted by adjusting the feeding mechanism. The capacity is 6200 setts per hour. It works on the principle of impact shear, giving clean cut without splitting of buds.

2. Power Operated Maize Dehusker-cum-Sheller: The machine is operated by a 1.5 - 2 hp electric motor. It has two units - dehusking unit and shelling unit. First, the maize cobs with husk are fed to the dehusking rollers which are made of rubber rollers rotating in opposite directions. The husk is stripped off by rubbing action. Then the dehusked cobs go to the shelling unit consisting of a spike tooth cylinder and concave. The rotating cylinder beats the cobs and the grains are separated by impact and rubbing action against the concave. The grains fall through sieve and cleaned with blower. Capacity is 300-350 kg/hr.

3. Tractor Operated Sugarcane Seedling Transplanter: It is a tractor drawn, PTO operated 2-row transplanter. It consists of a frame, seedling trays, rotary cups/conveyors, furrow openers, and covering device. The 15-20 days old single-bud settlings grown in protrays are placed in the rotating cups. As the cups rotate, they drop one seedling at a time into the furrow opened by the furrow opener. The covering device covers the seedling with soil and press wheels firm the soil. Row to row spacing of 5 feet is maintained. Field capacity is 0.35-0.40 ha/h. It works on gravity drop and positive feeding principle.

***4. Tractor Operated Sugarcane Leaf Shredder cum Detrasher*:** High speed chopping and shredding by flails / blades. It is tractor PTO operated machine fitted with a high speed rotor (1500-1800 rpm) carrying Y-shaped or L-shaped blades / flails. When the tractor moves forward, the standing dry and green leaves of sugarcane are cut and shredded into small pieces by the high speed impact cutting of flails. The shredded leaves are spread in the field as mulch. The machine

works on the principle of free impact cutting - there is no counter shear plate, cutting is by high speed impact. It covers 0.40 ha in 2 hours and helps to avoid burning of trash, adds organic matter to soil.

Summary of Front Line Demonstrations:

S. N.	Name of equipment	No. of demonstrations conducted	Benefited farmers	Area (ha)	Total duration (h)	Progress made on commercialization
1	Sugarcane sett cutter	15	1483	70 t	85 h	12 farmers have purchased the device and set up their own nurseries
2	Maize sheller	23	1496	3.68 t	70 h	Farmers are requesting to make the device available for hire
3	Sugarcane seedling transplanter	16	1809	10.70 ha	35 h	Farmers are requesting to make the device available for hire
4	Sugarcane leaf shredder	6	876	1.31 ha	10h	Raising awareness about its benefits

Results and Discussion:

1. Power Operated Sugarcane Sett Cutter: The sett cutter was demonstrated at 15 locations in Mandya district. A total of 70 tonnes of sugarcane was cut in 85 hours of operation, benefiting 1483 farmers (1131 Male + 352 Female).The machine has a capacity of 6200 setts per hour with uniform size, ensuring better germination and rapid planting. It eliminates drudgery of manual cutting with axe and avoids injury. 12 farmers have purchased the unit after seeing demonstration and started custom hiring and sugarcane nursery business for additional income. It has become a game-changer for sugarcane seed production.

Plate 1: FLD of sett cutter conducted at research station and farmers field



2. Power Operated Maize Dehusker-cum-Sheller: This equipment was demonstrated at 23 locations, covering 3680 kg of maize in 70 hours and benefiting 1496 farmers. The machine performs both dehusking and shelling simultaneously with a capacity of 320 kg/h. It reduces post-harvest losses, saves 80% labour and time compared to manual shelling, and gives clean grains. Farmers appreciated its performance and requested to place the machine in Custom Hiring Centres (CHC) established by KSDA for easy hiring.

Plate 2: FLD of maize sheller conducted at research station and farmers field



3. Tractor Operated Sugarcane Seedling Transplanter: The transplanter for 15-20 days old single bud chip seedlings was demonstrated in 16 farmers' fields covering 10.70 ha in 35 hours, benefiting 1809 farmers - the highest among all demonstrations. The machine has a field capacity of 0.40 ha/h and requires only 6000-6500 seedlings per acre as against 3 times higher seed rate in conventional planting. It is a wide-space, labour-saving technology and ensures uniform plant population. There is high demand for this technology. Farmers have requested to make it available in CHC centres.

Plate 3: FLD of sugarcane seedling transplanter conducted at research station and farmers field




4. Tractor Operated Sugarcane Leaf Shredder cum Detrasher: This machine was demonstrated at 6 locations covering 1.31 ha in 10 hours, benefiting 876 farmers. The shredder is used for detrashing leaves before harvest and shredding during intercultivation. It covers 0.40 ha in 2 hours. The shredded trash acts as mulch, enhances soil fertility, avoids trash burning and reduces environmental pollution.

Plate 4: FLD of sugarcane leaf detrasher cum shredder conducted at farmers field




Inference: The front line demonstrations proved to be a very effective method for popularization of improved farm implements. All four machines demonstrated significant savings in time (70-80%), labour (75-90%) and cost of operation (50-70%) compared to traditional methods. The demonstrations have created a wide awareness among 5664 farmers and farm women of Mandya district. The adoption by 12 farmers for custom hiring and demand for inclusion of these machines in Custom Hiring Centres indicates their economic viability and practical utility. Such FLDs need to be continued in more clusters to achieve faster farm mechanization, reduce drudgery of farm women and youth, and to make agriculture profitable and sustainable.

Volume: 06 Issue No: 09

RIGHTS-BASED FISHERIES MANAGEMENT: A PATHWAY TO SUSTAINABLE, EQUITABLE AND EFFICIENT FISHERIES

Article ID: AG-V06-I09-111

Aatepogu Revathi*, Pugazhenthi.P, Shaik Haseena and Amin Binth Basheer

ICAR- Central Institute of Fisheries Education, Mumbai- 400061, India.

*Corresponding Author: Aatepogu Revathi

Abstract

Rights-based fisheries management (RBM) provides a practical approach to reducing overfishing and promoting sustainable use of fishery resources. It assigns clear access, use, or harvest rights to individuals, groups, or communities, reducing competition and encouraging responsible fishing practices. Major approaches include Territorial Use Rights in Fisheries (TURFs), limited entry, harvest quotas, and Individual Transferable Quotas (ITQs). RBM can improve ecological sustainability, economic efficiency, and the livelihoods of fishing communities. Its effectiveness depends on fair allocation of rights, proper monitoring, effective enforcement, and protection of small-scale fishers. Thus, well-designed RBM can support sustainable fisheries while balancing environmental, economic, and social objectives.

Keywords: Rights-based fisheries management; Property rights; Use rights; TURFs; Sustainable fisheries.

1.Introduction

The world's fisheries are facing increasing pressure due to rising demand for seafood, technological advancements in fishing, and growing fishing capacity. In many parts of the world, fisheries have historically operated under open-access systems, where anyone can fish without clear restrictions on entry. While this approach may seem fair, it often leads to serious problems such as overfishing, depletion of fish stocks, and economic inefficiency. Open-access fisheries are considered common-pool resources, meaning they are both rivalrous and non-excludable. When one fisher catches fish, fewer fish remain for others, making the resource rivalrous. At the same time, it is difficult to prevent others from entering the fishery, making it non-excludable.

As a result, fishers compete to harvest as much fish as possible before others do, creating what economists describe as the "race to fish." This uncontrolled competition can eventually lead to the collapse of fish stocks and loss of livelihoods for fishing communities. Recognizing these challenges, fisheries managers and policymakers around the world have increasingly adopted rights-based fisheries management (RBM) as a strategy to ensure sustainability and economic efficiency.

1.1. Rights-Based Fisheries Management

RBM is an approach that allocates specific fishing rights to individuals, groups, or communities. These rights may include permission to harvest a certain amount of fish, use a defined level of fishing effort, or operate within a particular fishing area. Under RBM systems, fishers are given secure and clearly defined rights to access and utilize fishery resources. Because these rights are protected, fishers are less likely to engage in destructive competition and are more likely to adopt responsible fishing practices. The concept directly addresses the "Tragedy of the Commons," first described by Garrett Hardin in 1968. In an open-access fishery, each fisher tries to maximise individual catch without considering the long-term consequences for the resource. RBM transforms fishers from short-term exploiters into long-term stewards of the resource. Although RBM may seem like a modern management approach, similar systems have existed for centuries in many traditional fishing communities.

1.2.Balancing the Needs of People, the Ocean, and the Economy

RBM aims to balance three key objectives: ecological sustainability, economic efficiency, and social equity. When fishers are given secure fishing rights, they have a strong incentive to protect fish stocks and support conservation measures. Instead of racing to catch as much as possible, fishers focus on maximising the long-term value of the fishery. RBM systems have also been shown to improve economic performance in fisheries. By reducing excessive competition, fishers can operate more efficiently, reduce operating costs, and improve product quality. As a result, profitability in the fishing industry often increases. At the same time, well-designed RBM systems can address social concerns by protecting the interests of small-scale fishers and fishing-dependent communities. Transparent allocation of fishing rights and community participation in management decisions help build trust and ensure fair distribution of benefits.

1.3. Property Rights in Fisheries:

Understanding rights-based fisheries management requires an understanding of property rights regimes. Property rights define who has the authority to access, use, manage, and benefit from a resource. There are four major types of property regimes in fisheries:

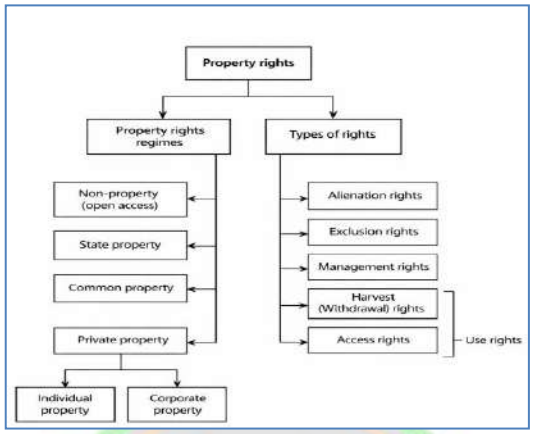


Figure 1. Classification of Property Rights Regimes and Types of Property Rights

1.3.1.Non-Property (Open Access)

In open-access systems, no individual or group has exclusive rights to the resource. Fish stocks in international waters historically operated under this system, allowing anyone to fish without restrictions.

1.3.2.Private Property

In some cases, fish resources can become private property. For example, fish caught and brought onto a vessel immediately become the property of the fisher. Similarly, fish in privately owned ponds or lakes may belong to the landowner.

Types: 1. Individual property **2.** Corporate property

1.3.3. State Property

In many nations, fish in the oceans are considered the property of the nation's citizens, and are controlled on their behalf by the government. Legally, the government (the 'state') owns the resource, and hence this is referred to as a case of 'state property'. The perception of 'state property' is very different in the natural resource context from its use in daily discourse. Whereas state-owned corporations can be sold off in their entirety, natural resources owned by the state (forests, fish in the ocean, minerals and oil in the ground) typically cannot be privatized without legislation, or perhaps even constitutional change. Certainly, these resources can be extracted, thereby becoming private property, but in their original location, they remain state property.

1.4 Use Rights in Fisheries

Use rights in fisheries refer to the rights granted or recognized for individuals, groups, communities or fishing sectors to access and utilize fishery resources. They help define who can participate in a fishery, where fishing can take place, the level of fishing effort that can be used, and the quantity of fish that can be harvested. From a management perspective, use rights can broadly be classified into access rights and harvest or withdrawal rights (Charles, 2002).

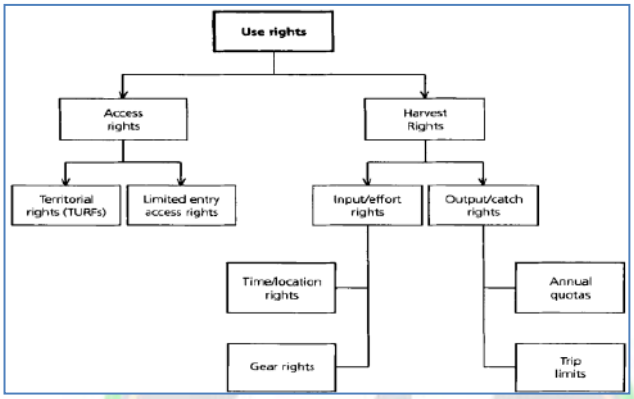


Figure 2. Classification of Use Rights

1.4.1.Access Rights:

Access rights determine the entitlement to enter or participate in a fishery or to use a particular fishing area. Two important forms are Territorial Use Rights in Fisheries (TURFs) and limited-entry rights.

A. TURFs provide individuals, groups or communities with recognized rights to fish within a clearly defined geographical area. Such arrangements can be particularly relevant where fishing activities are closely associated with specific fishing grounds or relatively sedentary resources.A well-known example is the TURF system in Chile, where artisanal fishing communities manage coastal areas for harvesting species such as sea urchins and shellfish. The Chilean government introduced this system through the General Fisheries and Aquaculture Law of 1991, allowing communities to manage local marine resources sustainably.

B. Limited-entry rights restrict participation in a fishery by allowing only a specified number of fishers or fishing vessels to operate, generally through licences or permits. The purpose is to control the number of participants and thereby limit excessive fishing capacity and pressure on the resource (Charles, 2002; FAO, 2003). By controlling entry into the fishery, authorities can reduce fishing pressure and improve economic returns for license holders.

However, limited entry systems also have limitations. Even when the number of vessels is restricted, fishers may invest in larger boats, advanced equipment, or more efficient gear, increasing their fishing capacity. This phenomenon is known as "capital stuffing." Therefore, limited entry policies are often combined with other management tools such as quotas or spatial restrictions.

Harvest Quotas and Total Allowable Catch

Harvest quotas are another important tool in rights-based fisheries management. The most common approach is the Total Allowable Catch (TAC) system, which sets a limit on the total quantity of fish that can be harvested from a particular stock during a specific period. The TAC is usually divided among sectors, communities, or individual fishers, giving them a defined share of the allowable catch. One widely used system is Individual Quotas (IQs), where each fisher receives a fixed share of the total allowable catch. These quotas can be either transferable or non-transferable. In Individual Transferable Quota (ITQ) systems, fishers can buy or sell their quota shares.Another variation is community quotas, where a fishing community or cooperative receives a collective share of the total allowable catch and manages it internally. This approach strengthens community participation and local governance in fisheries management.

1.4.2.Withdrawal or Harvest Rights:-

Harvest or withdrawal rights determine the extent to which an authorised fisher can utilize the fishery resource. These rights can be established either through input/effort controls or through output/catch controls.

A.Input or effort rights regulate the amount of fishing activity that can be undertaken, such as the number of fishing days, vessel capacity, fishing gear or other fishing inputs.

B. Output or catch rights directly regulate the quantity of fish that may be harvested. A total allowable catch can be divided among individual fishers, fishing groups, communities or sectors in the form of quotas. These may include annual quotas, which specify the quantity that can be harvested over a defined period, and trip limits, which restrict the quantity of fish that can be landed during an individual fishing trip. Thus, input rights control how much fishing effort is used, whereas output rights control how much fish can be harvested

1.5.Challenges in Rights-Based Fisheries

Despite its advantages, rights-based fisheries management also faces several challenges. If fishing inputs such as vessel size or gear type are not carefully regulated, fishers

may attempt to increase their fishing capacity to maximize their catch. Technological advancements can also increase fishing efficiency, making it difficult for regulators to control total fishing effort. In addition, poorly designed RBM systems may lead to inequality in the distribution of fishing rights, potentially disadvantaging small-scale fishers. Therefore, effective RBM systems require strong monitoring, enforcement, and transparent governance structures.

1.6.Best Practices for Rights-Based Fisheries

- Successful RBM programs follow several key principles:
- Science-based conservation targets should guide decisions about allowable catch or fishing effort.
- Transparency and fairness are essential when allocating fishing rights.
- Effective monitoring and enforcement must ensure compliance with management rules.
- Fishing rights should also be secure, exclusive, and transferable, allowing fishers to plan for the long term while preventing excessive fishing capacity.
- At the same time, policymakers must ensure that small-scale fishers and fishing communities are protected from being excluded from the fishery.

1.7. Common Property

While historically, the above forms of property have received most attention in studies of resources within the Western world, common property is pervasive worldwide, and in recent years has become a major topic of property rights theory. Common property resources, such as fish swimming in the sea, are those held 'in common' by a certain identifiable group of people Groups holding common property have collective-choice rights and can seek to establish rules for access, use and management. Examples of such groups include the citizens of a specific local jurisdiction (community) or the members of a native tribe, but not a private individual or company. Note that if the group were defined very widely, as all the citizens of a nation, this would be a case of state property. Indeed in common usage, the fishery resources of a nation are often referred to as common property, rather than state property, although in common property theory, a smaller, more cohesive group is usually envisioned.

Management rights: the right to make rules for fishing. Example: In Chilika Lake, fishing communities decide rules such as fishing time, gear used, and effort limits through local bylaws.

Exclusion rights: the right to stop outsiders from fishing.

Alienation rights: right to sell or lease fishing rights, as in ITQ systems where fishers can transfer their quota share to others without increasing total catch.

Conclusion

Rights-based fisheries management has emerged as one of the most promising approaches for addressing the challenges of overfishing and declining fish stocks. By allocating clear and secure fishing rights, RBM systems encourage fishers to adopt responsible harvesting practices and invest in the long-term sustainability of marine resources. When designed carefully, rights-based fisheries can balance ecological conservation, economic efficiency, and social equity. They help reduce the destructive race for fish, improve profitability in the fishing sector, and promote better stewardship of marine ecosystems. As global demand for seafood continues to grow, adopting innovative management approaches such as RBM will be essential to ensure that fisheries remain productive and sustainable for future generations

References

Bromley, D.W., 1991. *Environment and economy: Property rights and public policy* (pp. xi+-247pp).

Charles, A.T., 2002. Use rights and responsible fisheries: limiting access and harvesting through rights-based management. *FAO Fisheries Technical Paper*, pp.131-158.

Christy, F.T., 1982. *Territorial use rights in marine fisheries: definitions and conditions* (Vol. 227). Food & Agriculture Org.

Ciriacy-Wantrup, S.V. and Bishop, R.C., 1975. " Common property" as a concept in natural resources policy. *Natural resources journal*, *15*(4), pp.713-727.

Costello, C., Gaines, S.D. and Lynham, J., 2008. Can catch shares prevent fisheries collapse?. *Science*, *321*(5896), pp.1678-1681.

Food and Agriculture Organization. (2022). *The State of World Fisheries and Aquaculture 2022: Towards Blue Transformation*. Rome: FAO.

Grafton, R.Q., Arnason, R., Bjørndal, T., Campbell, D., Campbell, H.F., Clark, C.W., Connor, R., Dupont, D.P., Hannesson, R., Hilborn, R. and Kirkley, J.E., 2006. Incentive-based approaches to sustainable fisheries. *Canadian Journal of Fisheries and Aquatic Sciences*, *63*(3), pp.699-710.

Hardin, G., 2009. The tragedy of the commons. *Journal of Natural Resources Policy Research*, *1*(3), pp.243-253.

Lobe, K., & Berkes, F. (2004). The Padu system of community-based fisheries management: Change and local institutional resilience in a South Indian lagoon. *Marine Policy,* 28(3), 271–281

Ostrom, E., 1990. *Governing the commons: The evolution of institutions for collective action* (Vol. 10). Cambridge: Cambridge university press.

Reimer, M.N. and Wilen, J.E., 2013. Regulated open access and regulated restricted access fisheries. *Encyclopedia of energy, natural resource, and environmental economics*, *2*, pp.215-33.

Schlager, E. and Ostrom, E., 1992. Property-rights regimes and natural resources: a conceptual analysis. *Land economics*, pp.249-262.

Scott, A., 1955. The fishery: the objectives of sole ownership. *Journal of political Economy*, *63*(2), pp.116-124.

World Bank, FAO, 2009. The sunken billions: The economic justification for fisheries reform.

Volume: 06 Issue No: 09

GENOME EDITING AND TRANSGENIC TECHNIQUES IN IMPROVEMENTS OF GRAPE, POTATO AND TOMATO

Article ID: AG-VO6-I09-112

[1]Gayathri K B, [1]Afrin Frank B S, [1]Durga Prasad T S, [1]Keshav Meena,

[1] Akshay K and [2]Sivaji M.

[1]UG Student, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu 606 753

[2]Teaching Assistant Agricultural Biotechnology, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu 606 753

Corresponding Author: Gayathri K B

Introduction

Grape (*Vitis vinifera* L.), potato (*Solanum tuberosum* L.), and tomato (*Solanum lycopersicum* L.) are important horticultural crops cultivated worldwide. Grapes are consumed as fresh fruits and are also processed into raisins, juice, and wine. Potatoes are widely used as food and processed into chips, French fries, and starch, while tomatoes are consumed fresh and processed into ketchup, sauce, paste, puree, and juice. Traditional breeding has contributed greatly to the improvement of these crops, but it is often time-consuming and has certain limitations, including limited availability of desirable genes and difficulty in combining several useful traits. Modern biotechnological approaches, particularly genome editing and transgenic techniques, provide more targeted methods for crop improvement.

Genome editing involves making targeted changes to specific genes already present in the plant, whereas transgenic technology introduces an additional useful gene from the same or another organism. These technologies can be used to improve yield, disease and pest resistance, drought and salinity tolerance, fruit quality, nutritional value, and shelf life. They also support the development of climate-resilient and high-quality crop varieties, which can contribute to sustainable agricultural production and reduced dependence on pesticides.

Genome Editing:

Genome editing is a modern biotechnology that enables precise and targeted changes in a plant's DNA. It can be used to add, remove, or modify specific genes to improve important traits without altering the entire genome. Compared with conventional breeding, genome editing can provide a faster and more targeted approach for plant improvement.

The major genome-editing tools include CRISPR-Cas9, TALENs (Transcription Activator-Like Effector Nucleases), and ZFNs (Zinc Finger Nucleases). Among these, CRISPR-Cas9 is the most widely used system. It uses a guide RNA (gRNA) to identify the target DNA sequence, while the Cas9 enzyme makes a cut at the selected site. TALENs use engineered DNA-binding proteins to recognize specific DNA sequences and introduce targeted DNA cuts. ZFNs are engineered nucleases that use zinc-finger proteins to recognize specific DNA sequences and make targeted changes. These tools enable researchers to modify genes associated with disease resistance, stress tolerance, yield, fruit quality, and other desirable traits.

Transgenic Techniques:

Transgenic technology is a biotechnology method used to introduce a useful gene into a plant to improve a desired trait. The introduced gene is called a transgene and may be obtained from another plant, bacterium, fungus, or the same plant species. Unlike genome editing, which mainly changes an existing gene at a specific location, transgenic technology generally introduces an additional gene into the plant genome.

The major methods used for gene transfer include Agrobacterium-mediated transformation, particle bombardment, electroporation, and microinjection. In Agrobacterium-mediated transformation, the desired gene is inserted into a suitable vector and transferred into plant cells using Agrobacterium tumefaciens. The transformed cells are then selected and regenerated into complete plants. In particle bombardment, DNA-coated gold or tungsten particles are directly introduced into plant cells using a gene gun. In electroporation, short electrical pulses create temporary pores in cell membranes, allowing DNA to enter the cells. In microinjection, the desired DNA is directly introduced into individual plant cells using a fine glass needle.

Genome Editing And Transgenic Techniques In Improvement Of Grape (*Vitis Vinifera* L.)

Grape (*Vitis vinifera* L.) belongs to the family Vitaceae and is one of the oldest and important fruit crops in the world. Grapes are eaten fresh and are also used to make raisins,

juice, jam, jelly, vinegar, and wine. They contain vitamins, minerals, antioxidants, flavonoids, and resveratrol, which are beneficial to health.

Grape production is affected by fungal diseases such as powdery mildew, downy mildew, and gray mold, and viral diseases such as grapevine leafroll virus and grapevine fanleaf virus. Insect pests such as mealybugs, thrips, and stem borers also cause damage. Abiotic stresses such as drought, heat, salinity, and cold can reduce grape growth and yield.

Conventional breeding in grape is slow and difficult because of its long juvenile period and high genetic variability. Therefore, genome editing and transgenic techniques are used to develop improved grape varieties with better disease resistance, pest resistance, stress tolerance, and fruit quality.

Important genes edited in grape:

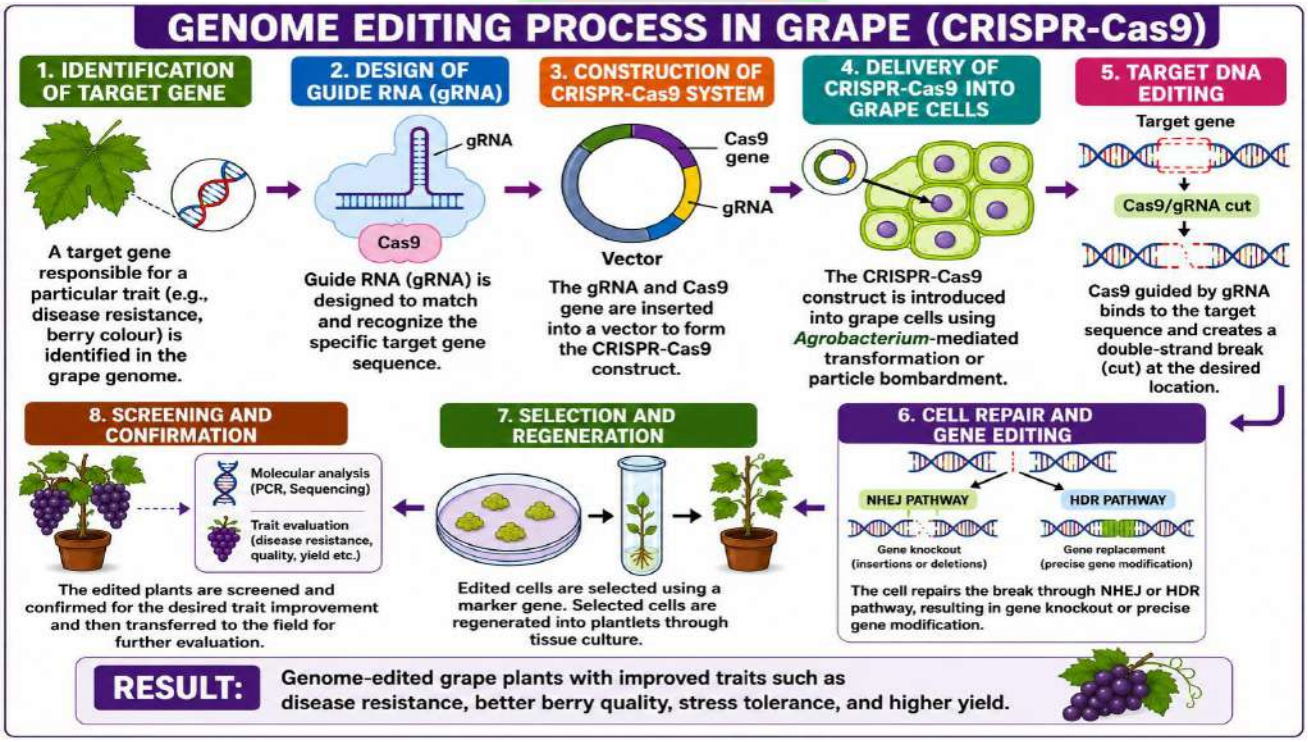


Figure 1 – GENOME EDITING PROCESS IN GRAPES via CRISPR-Cas9

1. MLO Gene: MLO genes are associated with susceptibility to powdery mildew. Editing specific VvMLO genes, such as VvMLO3 and VvMLO4, can reduce susceptibility and improve resistance to powdery mildew caused by Erysiphe necator.

2. DMR6 Gene: VvDMR6-1 and VvDMR6-2 are susceptibility genes involved in plant immunity. Their knockout can reduce susceptibility to downy mildew caused by *Plasmopara viticola* and enhance disease resistance.
3. WRKY52 Gene: VvWRKY52 is a transcription factor involved in plant defence responses. Its knockout has been shown to increase resistance to *Botrytis cinerea*, the causal organism of grey rot/noble rot.
4. PDS Gene: VvPDS (Phytoene Desaturase) is involved in carotenoid biosynthesis. Its disruption produces an albino phenotype, making it useful as a visible marker for confirming genome-editing activity in grapevine.
5. CCD8 Gene: VvCCD8 (Carotenoid Cleavage Dioxygenase 8) is involved in strigolactone biosynthesis and shoot-branching regulation. Its knockout results in increased shoot branching, thereby modifying grapevine shoot architecture.
6. MYBA Gene: VvMYBA genes are involved in anthocyanin accumulation and berry pigmentation. Modification of these genes can influence anthocyanin accumulation and berry colour. However, the effects can depend on the specific MYBA gene and genetic background.

Important Genes Used In Transgenic Grape:

1. VvSTS Gene – From *Vitis vinifera*. Increasing the activity of this gene increases stilbene and resveratrol production, which improves nutritional quality and plant defence.
2. AtDREB1A Gene – From *Arabidopsis thaliana.* Introducing this gene helps grape plants tolerate drought stress by activating stress-responsive mechanisms.
3. HVA1 Gene – From *Hordeum vulgare* (barley). Introducing this gene helps improve drought and osmotic-stress tolerance by protecting plant cells.
4. AtNHX1 Gene – From *Arabidopsis thaliana*. Introducing this gene helps grape plants tolerate salt stress by controlling excess sodium inside the cells.
5. VvP5CS Gene – From *Vitis vinifera*. Increasing the activity of this gene increases proline production, which helps improve tolerance to drought and salinity.

Genome Editing And Transgenic Techniques In Improvement Of Potato (*Solanum Tuberosum* L.)

Potato (*Solanum tuberosum* L.) belongs to the family Solanaceae and is one of the most important food crops in the world. It is mainly used as food and is also processed into chips,

French fries, starch, and flakes. Potato is rich in carbohydrates, vitamin C, potassium, fiber, and minerals.

Potato production is affected by diseases such as late blight, early blight, bacterial wilt, PVY, and PLRV. Insect pests such as aphids and Colorado potato beetle also cause damage. Drought, heat, salinity, cold, and poor storage can also reduce production and quality.

Conventional breeding in potato is difficult because it has a complex tetraploid genome and is mainly propagated through tubers. Therefore, genome editing and transgenic techniques are used to develop potato varieties with improved disease and pest resistance, stress tolerance, quality, and storage life.

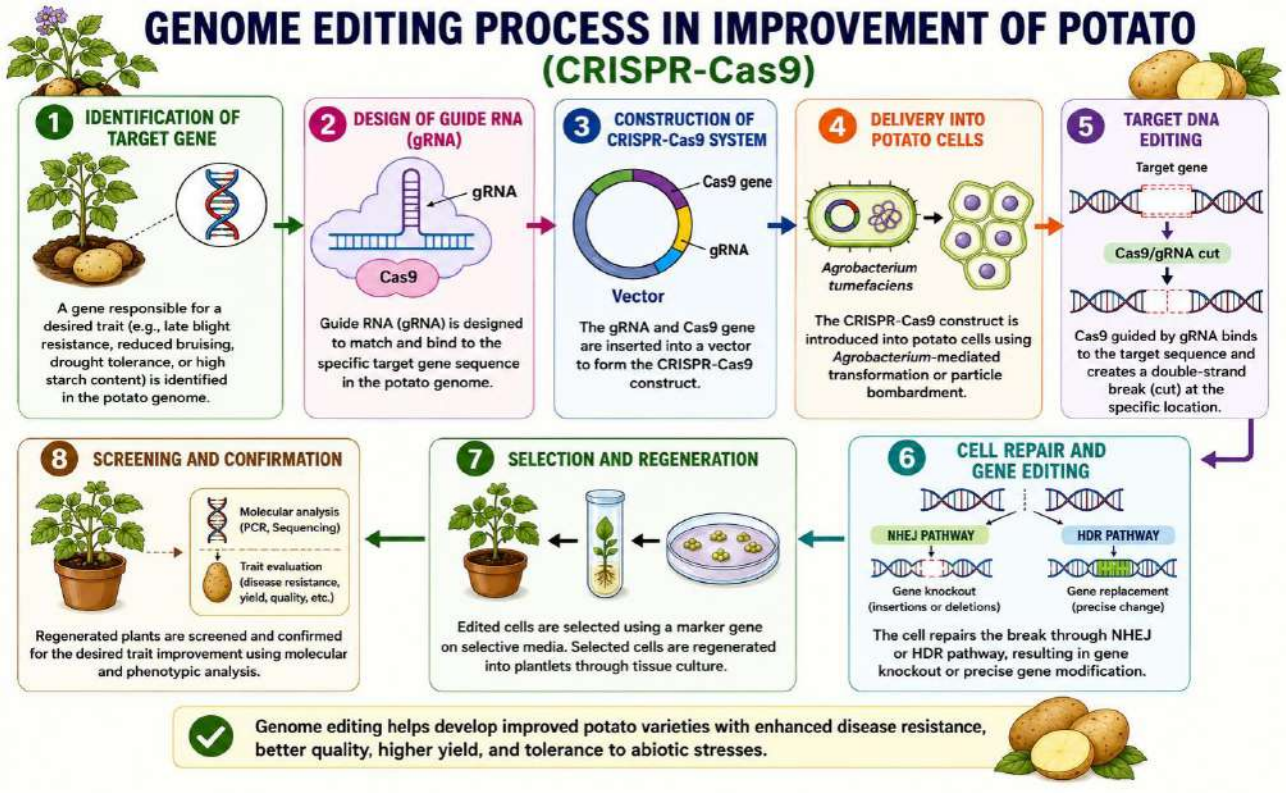


Figure 2. GENOME EDITING PROCESS IN POTATO via CRISPR-Cas9

Important genes edited in potato:

GBSS Gene (Granule-Bound Starch Synthase) – This gene controls amylose production in potato tubers. Editing it can produce waxy potatoes with improved starch quality.

1. StPPO Gene (Polyphenol Oxidase) – This gene is involved in browning of potato tubers. Editing it can reduce browning and improve tuber quality.

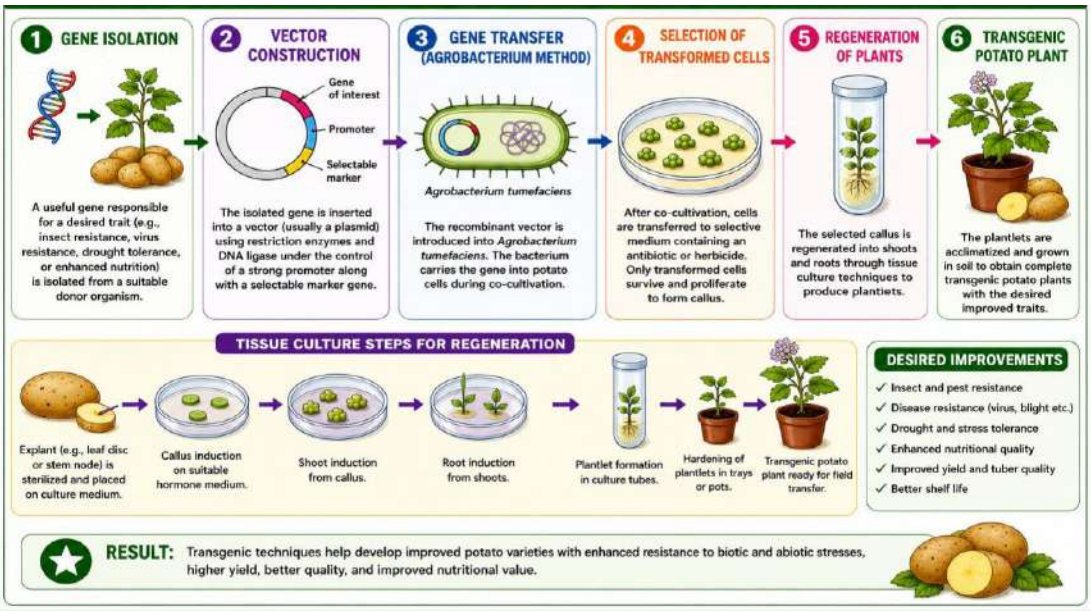
2. VInv Gene (Vacuolar Invertase) – This gene converts sucrose into reducing sugars during cold storage. Editing it can reduce sugar accumulation and acrylamide formation during frying.
3. StDMR6 Gene – This gene is involved in plant susceptibility to diseases. Editing it can improve disease resistance.
4. StALS Gene (Acetolactate Synthase) – This gene is involved in the plant's response to certain herbicides. Editing it can help develop herbicide-tolerant potato plants.
5. StSWEET11 Gene – This gene is involved in sugar transport in potato. Modification of this gene can affect sugar movement and may contribute to improved resistance to bacterial pathogens.
6. StFAD2 Gene (Fatty Acid Desaturase 2) – This gene is involved in fatty-acid composition. Editing it can modify the fatty-acid profile of potato tubers, which may improve nutritional and processing quality.
7. StRGA2 Gene – This gene is associated with resistance to late blight, one of the most important potato diseases. Modification of the StRGA2 resistance gene can contribute to improved late-blight resistance.

Important genes used in transgenic potato:

1. Bt Gene – From *Bacillus thuringiensis*. Introducing this gene helps potato plants produce an insecticidal protein that provides resistance against Colorado potato beetle and other insect pests.
2. RB Gene – From wild potato *Solanum bulbocastanum*. Introducing this gene provides resistance to late blight caused by Phytophthora infestans.
3. CP Gene (Coat Protein Gene) – Obtained from potato viruses such as Potato virus Y (PVY). Introducing the viral coat protein gene can provide resistance to viral infection.
4. HVA1 Gene – From barley (*Hordeum vulgare*). Introducing this gene can improve drought and osmotic-stress tolerance by helping protect plant cells during water stress.
5. AtNHX1 Gene – From *Arabidopsis thaliana*. Introducing this gene can improve salt tolerance by helping potato plants control excess sodium ions.
6. P5CS Gene – Involved in proline production. Introducing or increasing the activity of this gene can increase proline accumulation and improve drought and salinity tolerance

Figure 3. TRANGENIC TECHNOLOGY IN IMPROVEMENT OF POTATO

.



Genome Editing And Transgenic Techniques In Improvement Of Tomato (*Solanum Lycopersicum* L.)

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop belonging to the family Solanaceae and is widely cultivated throughout the world. It is consumed fresh and is also processed into ketchup, sauce, puree, paste, juice, soup, and canned products. Tomato fruits are rich in vitamin C, vitamin A, lycopene, β-carotene, antioxidants, and minerals, making them nutritionally important.

Tomato production is affected by several biotic stresses, including diseases such as Tomato yellow leaf curl virus (TYLCV), bacterial wilt, early blight, late blight, and powdery mildew, as well as insect pests such as fruit borer, whiteflies, aphids, & thrips. Abiotic stresses, including drought, heat, salinity, and cold, can also reduce plant growth and yield. In addition, the short shelf life of ripe fruits can lead to post-harvest losses.

Conventional breeding can be time-consuming and has limitations in developing specific traits. Therefore, genome editing and transgenic techniques are increasingly used for tomato improvement. These approaches help develop varieties with improved yield, disease and pest resistance, stress tolerance, fruit quality, nutritional value, and extended shelf life.

Important genes edited in tomato:

1. RIN Gene (RIPENING INHIBITOR) – This gene controls fruit ripening. Editing this gene can delay ripening and increase the shelf life of tomato fruits.
2. SlMLO1 Gene – This gene is associated with susceptibility to powdery mildew. Editing this gene can improve resistance to powdery mildew.
3. SlCLV3 Gene – This gene controls fruit development and fruit size. Editing this gene can increase fruit size and locule number.
4. SlDMR6 Gene – This gene is associated with susceptibility to diseases. Editing this gene can improve disease resistance.
5. SP5G Gene – This gene controls flowering time. Editing this gene can promote earlier flowering and fruit production.
6. SlMYB12 Gene – This gene regulates flavonoid and phenolic compound production. Editing this gene can improve fruit pigmentation and nutritional quality.
7. SlPDS Gene (Phytoene Desaturase) – This gene is involved in carotenoid production. Editing this gene produces a visible albino phenotype, making it useful for confirming genome-editing activity.

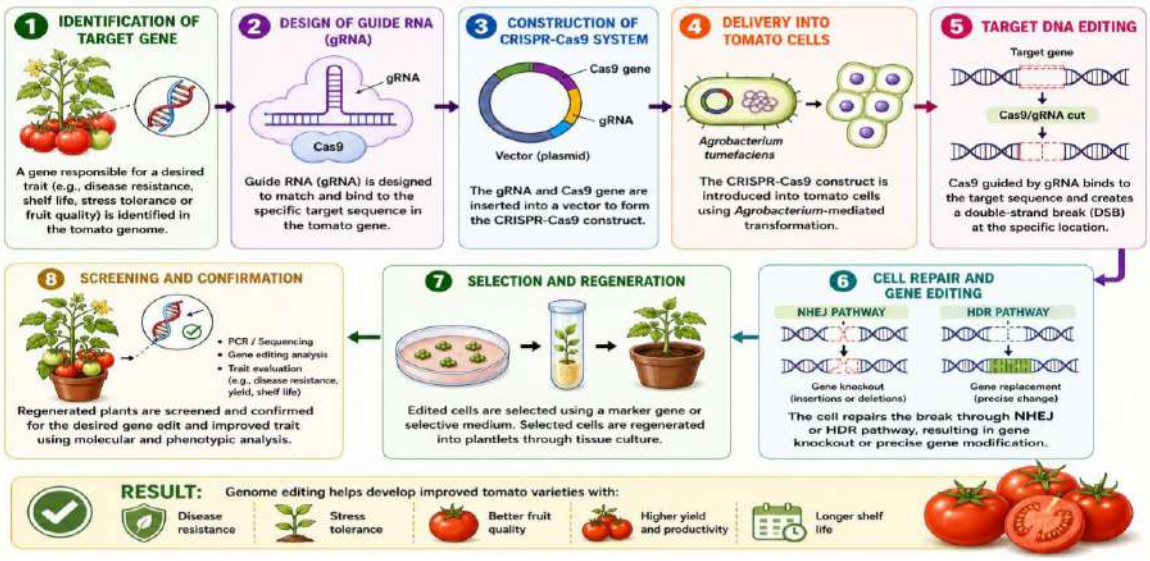


Figure 4 – GENOME EDITING PROCESS IN TOMATO

Important genes used in transgenic tomato:

1. Bt Gene – From *Bacillus thuringiensis.* Introducing this gene helps tomato plants produce an insecticidal protein that provides resistance against insect pests such as tomato fruit borer.

2. Antisense Polygalacturonase (PG) Gene – This gene reduces the activity of polygalacturonase, an enzyme involved in fruit softening. Its introduction delays fruit softening and increases shelf life.
3. CP Gene (Coat Protein Gene) – Derived from viruses such as Tomato mosaic virus (ToMV). Introducing the viral coat protein gene can provide resistance against viral infection.
4. Chitinase Gene – Introducing this gene increases the production of chitinase, an enzyme that breaks down fungal cell walls and helps improve resistance to fungal diseases.

5. Osmotin Gene – Introducing this gene helps tomato plants tolerate drought and salinity and can also contribute to resistance against some fungal pathogens.
6. Defensin Gene – This gene produces antimicrobial proteins that help protect tomato plants against bacterial and fungal pathogens.
7. Phytoene Synthase (PSY) Gene – Increasing the activity of this gene enhances carotenoid and lycopene production, which can improve the nutritional quality and antioxidant value of tomato fruits.

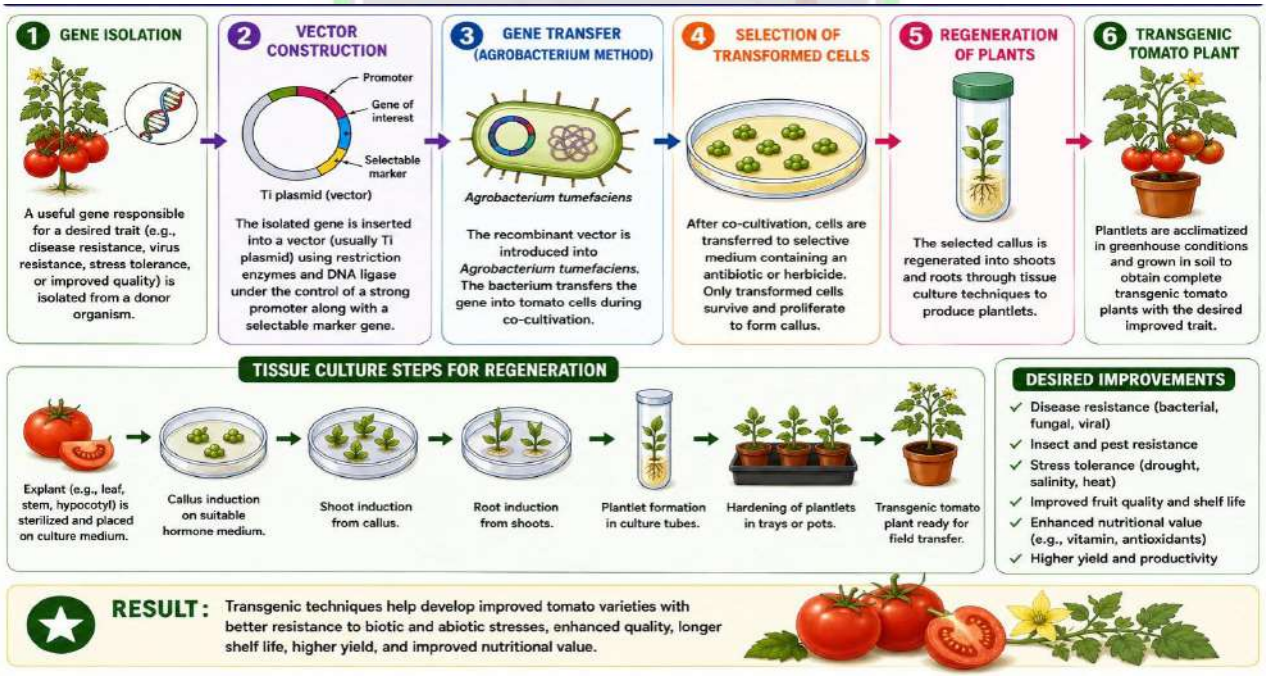


Figure 5 - TRANSGENIC TECHNOLOGY IN IMPROVEMENT OF TOMATO

Future prospects:

Genome editing and transgenic techniques have great potential for future crop improvement. Advanced tools such as CRISPR-Cas9, base editing, and prime editing can help develop improved grape, potato, and tomato varieties. These technologies can be used to improve disease and pest resistance, drought, heat and salinity tolerance, nutritional value, fruit and tuber quality, and shelf life. They can also help reduce pesticide use and post-harvest losses.

Multiplex genome editing can modify several genes at the same time and help improve multiple traits. Gene stacking can combine different useful traits in a single variety. The development of DNA-free genome-edited plants, along with the use of artificial intelligence (AI), genomic selection, and precision agriculture, can further speed up crop improvement. These developments can help produce high-yielding, climate-resilient, nutritious, and sustainable crops, contributing to food security and nutritional security.

Conclusion

Genome editing and transgenic techniques provide effective tools for improving grape, potato, and tomato. They can enhance yield, quality, nutritional value, disease and pest resistance, stress tolerance, and shelf life. In grape, these technologies improve disease resistance and berry quality; in potato, they improve disease resistance, starch quality, browning, and storage quality; and in tomato, they improve fruit quality, ripening, shelf life, and resistance to diseases and pests. Despite challenges such as regulatory requirements, cost, and public acceptance, advances in CRISPR-Cas9 and other technologies will support faster crop improvement and contribute to sustainable agriculture, food security, and nutritional security.

References

Langner, T., Kamoun, S., & Belhaj, K. (2018). CRISPR crops: Plant genome editing toward disease resistance. Annual Review of Phytopathology, 56, 479–512. https://www.annualreviews.org/content/journals/10.1146/annurev-phyto-080417-050158

Chincinska, I. A., Miklaszewska, M., & Sołtys-Kalina, D. (2023). Recent advances and challenges in potato improvement using CRISPR/Cas genome editing. Planta, 257, 25. https://doi.org/10.1007/s00425-022-04054-3

Tiwari, J. K., et al. (2022). CRISPR/Cas genome editing in potato: Current status and future perspectives. Frontiers in Genetics, 13, 827808. https://doi.org/10.3389/fgene.2022.827808

Campos, G., Chialva, C., Miras, S., & Lijavetzky, D. (2021). New technologies and strategies for grapevine breeding through genetic transformation. Frontiers in Plant Science, 12, 767522. https://doi.org/10.3389/fpls.2021.767522

Martínez-Prada, M. M., Curtin, S. J., & Gutiérrez-González, J. J. (2022). Potato improvement through genetic engineering. GM Crops & Food, 13(1), 479–496. https://doi.org/10.1080/21645698.2021.1993688

Shahwar, D., Ahn, N., Kim, D., Ahn, W., & Park, Y. (2023). Mutagenesis-based plant breeding approaches and genome engineering: A review focused on tomato. Mutation Research – Reviews in Mutation Research, 792, 108473. https://doi.org/10.1016/j.mrrev.2023.108473

Volume: 06 Issue No: 09

SECONDARY METABOLITES AND MEDICINAL PROPERTIES OF ALOE VERA AND PHYLLANTHUS SPECIES

Article ID: AG-V06-I09-113

[1]Keshav Meena, [1]Swapnajit Behera, [1]Akshay K, [1]Durga Prasad T S, [1]Gayathri K B, [2]Sivaji M

[1]UG Student, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu 606 753

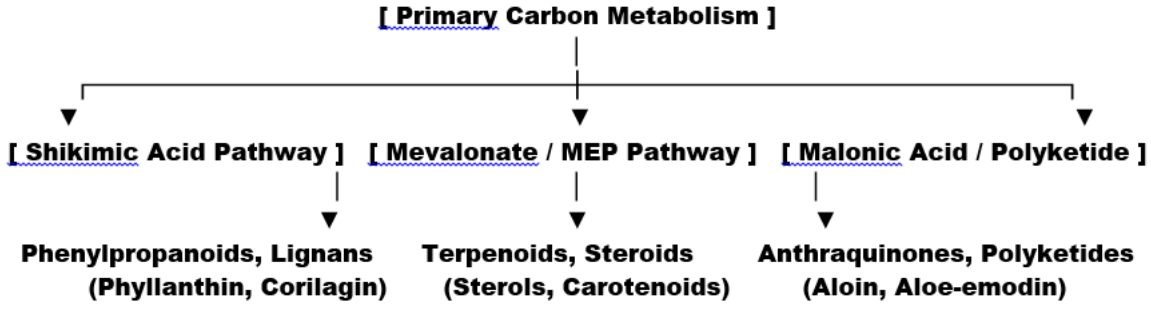
[2]Teaching Assistant Agricultural Biotechnology, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu 606 753

*Corresponding Author: Keshav Meena

Introduction

Plant secondary metabolites are organic compounds produced by plants that are not directly involved in basic growth, development, or reproduction. Unlike primary metabolites (proteins, lipids, carbohydrates, and nucleic acids), secondary metabolites are taxonomically restricted and serve specialized functional roles:

- **Ecological Adaptation:** Protection against biotic stress (herbivores, bacterial/fungal pathogens) and abiotic stress (UV radiation, drought, heavy metal toxicity).
- **Chemical Signaling:** Mediating interactions with pollinators, seed dispersers, and symbiotic soil microbes.
- **Pharmacological Value:** Serving as structural precursors or active ingredients for synthetic and herbal therapeutics.



In agricultural plant biotechnology, the study of secondary metabolism has shifted from traditional extraction to molecular breeding, tissue culture, and metabolic pathway engineering. By manipulating key enzymes and transcription factors, biotechnologists can overexpress high-value bioactive compounds in vitro, overcoming the limitations of wild-harvesting, seasonal yield fluctuations, and geographical constraints.

Aloe vera and species of the genus *Phyllanthus* represent two distinct botanical models exhibiting complex secondary metabolic profiles with significant commercial and therapeutic importance.

Botanical Profile and Taxonomic Classification

***Aloe vera* (L.) Burm.f.**

- **Family:** *Asphodelaceae* (formerly *Liliaceae* / *Xanthorrhoeaceae*)
- **Habitat & Distribution:** Arid, tropical, and subtropical regions worldwide.
- **Morphological Characteristics:** Perennial, xerophytic succulent characterized by turgid, lanceolate leaves with serrated margins arranged in a rosette formation.
- **Leaf Anatomy:** Anatomically partitioned into three distinct zones:
    1. **Cuticle / Outer Green Rind:** Rich in photosynthetic enzymes and specialized parenchymal tissue.
    2. **Vascular Bundles / Latex (Sap) Layer:** Located directly beneath the rind; contains specialized aloin-producing pericyclic cells.
    3. **Inner Parenchyma (Gel Matrix):** Colorless, mucilaginous parenchyma cells rich in hydrocolloidal polysaccharides (acemannan).

***Phyllanthus* Species (*P. amarus*, *P. niruri*, *P. emblica*)**

- **Family:** *Phyllanthaceae* (formerly Euphorbiaceae)
- **Key Species:**
    - ***Phyllanthus amarus* Schumach. & Thonn. / *Phyllanthus niruri* L.:** Small, erect annual herbs widespread in tropical and subtropical wasteland ecosystems.
    - ***Phyllanthus emblica* L. (Syn. *Emblica officinalis* Gaertn.):** A deciduous tree native to tropical Asia, producing nutrient-rich edible fruits ("Amla").
- **Morphological Characteristics:** Leaves are small, pinnately arranged or distichous; flowers are small, apetalous, and unisexual; fruits are small capsules or globose fleshy drupes.

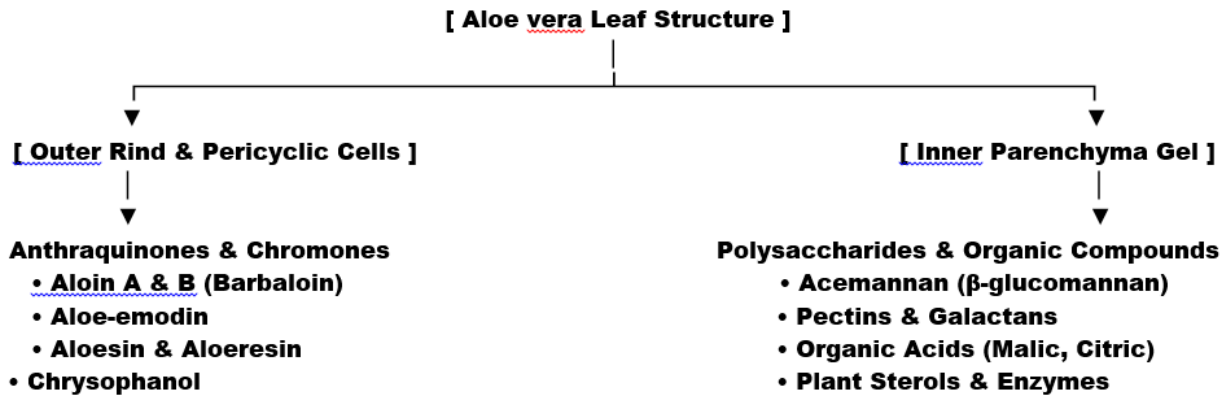
Botanical Parameter	**Aloe vera**	***Phyllanthus amarus / niruri***	***Phyllanthus emblica***
Growth Habit	Perennial xerophytic succulent	Annual erect herb	Deciduous medium tree
Primary Bioactive Part	Leaf exudate (latex) & inner gel	Whole aerial plant (leaves, stems)	Fleshy pericarp / fruit
Dominant Chemical Class	Anthraquinones, Chromones, Polysaccharides	Lignans, Hydrolyzable Tannins	Ellagitannins, Ascorbic acid derivatives
Biotechnological Focus	Tissue culture for micropropagation & aloin yield	Hairy root & suspension cultures for lignans	Micropropagation & fruit metabolite stability

Secondary Metabolite Profiling & Biosynthetic Pathways

Phytochemical Profile of *Aloe vera*

The bioactive profile of *Aloe vera* is divided between the yellow bitter latex (exudate) and the clear inner parenchyma gel.

Sterols & Enzymes



A. Anthraquinones & Anthrones (Latex Fraction)

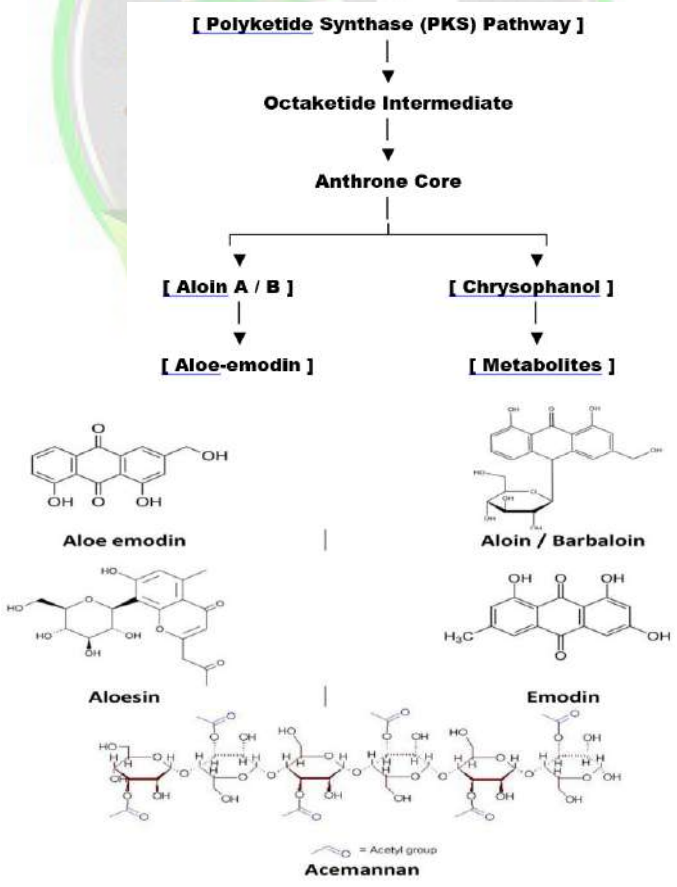
- **Aloin A & B (Barbaloin):** An anthrone C-glucoside representing the principal bitter exudate constituent. Biosynthesized via the polyketide pathway.
- **Aloe-emodin:** An oxidation product of aloin (1,8-dihydroxy-3-[hydroxymethyl]-anthraquinone). Exhibits significant cytotoxic and antiviral activities.
- **Chrysophanol:** A trihydroxy-methylanthraquinone involved in defense responses against fungal pathogens.

B. Chromones & Flavonoids

- **Aloesin (Aloesin A / Aloeresin A):** C-glucosylated 5-methylchromone exhibiting potent tyrosinase inhibitory and antioxidant properties.

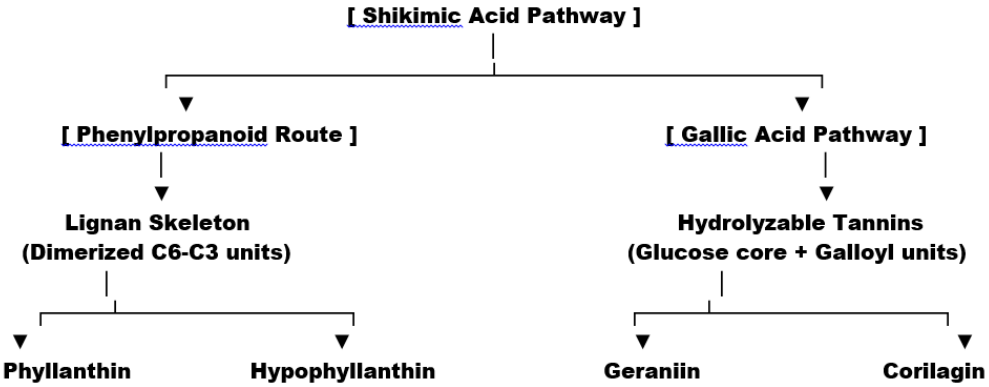
C. Polysaccharides & Hydrocolloids (Gel Fraction)

- **Acemannan:** A major acetylated β-(1,4)-D-glucomannan polysaccharide located within the inner parenchyma cell walls. It interacts directly with cell membrane receptors to exert immunomodulatory and tissue-regenerative effects (Sánchez et al., 2020).



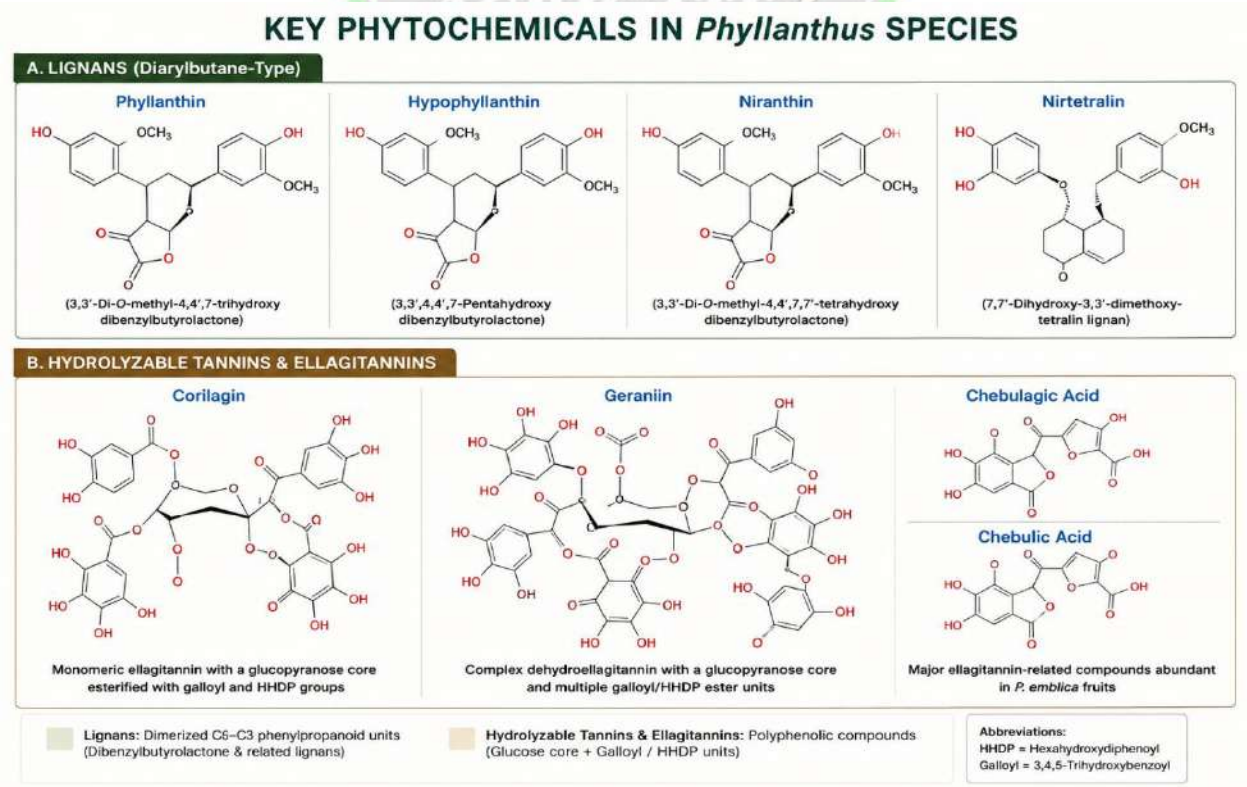
Phytochemical Profile of *Phyllanthus* Species

Species within the genus *Phyllanthus* synthesize a wide spectrum of specialized phenylpropanoid and tannin derivatives.



A. Lignans (Diarylbutane-Type)

- **Phyllanthin & Hypophyllanthin:** Major bioactive dibenzylbutyrolactones found primarily in *P. amarus* and *P. niruri*. These compounds exhibit strong hepatoprotective, antiviral, and anti-inflammatory properties (Nawfetrias et al., 2024).
- **Niranthin & Nirtetralin:** Related lignan derivatives with demonstrated anti-hepatitis B virus (HBV) activity and free radical scavenging capabilities.



B. Hydrolyzable Tannins & Ellagitannins

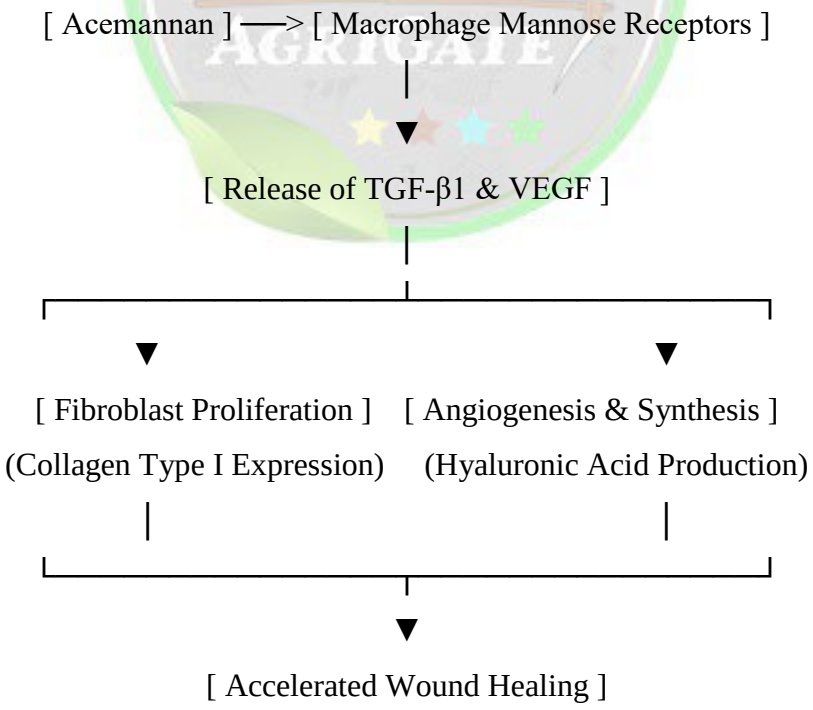
- **Corilagin:** A monomeric ellagitannin featuring a glucopyranose core esterified with gallic acid and hexahydroxydiphenic acid (HHDP).
- **Geraniin:** A complex dehydroellagitannin that serves as a major antioxidant in *Phyllanthus* foliage and fruit structures.
- **Chebulagic Acid & Chebulic Acid:** Major polyphenolic constituents present in high concentrations within *P. emblica* fruits.

Pharmacological & Medicinal Properties

Pharmacological Spectrum of *Aloe vera*

A. Wound Healing and Tissue Regeneration

- **Mechanism:** Acemannan binds to macrophage receptors (e.g., mannose receptors), stimulating the production of transforming growth factor-beta 1 (TGF-β1), vascular endothelial growth factor (VEGF), and basic fibroblast growth factor (bFGF).
- **Cellular Response:** Upregulates type I collagen synthesis, accelerates fibroblast proliferation, increases hyaluronic acid expression, and promotes capillary angiogenesis (Radha & Laxmipriya, 2015).

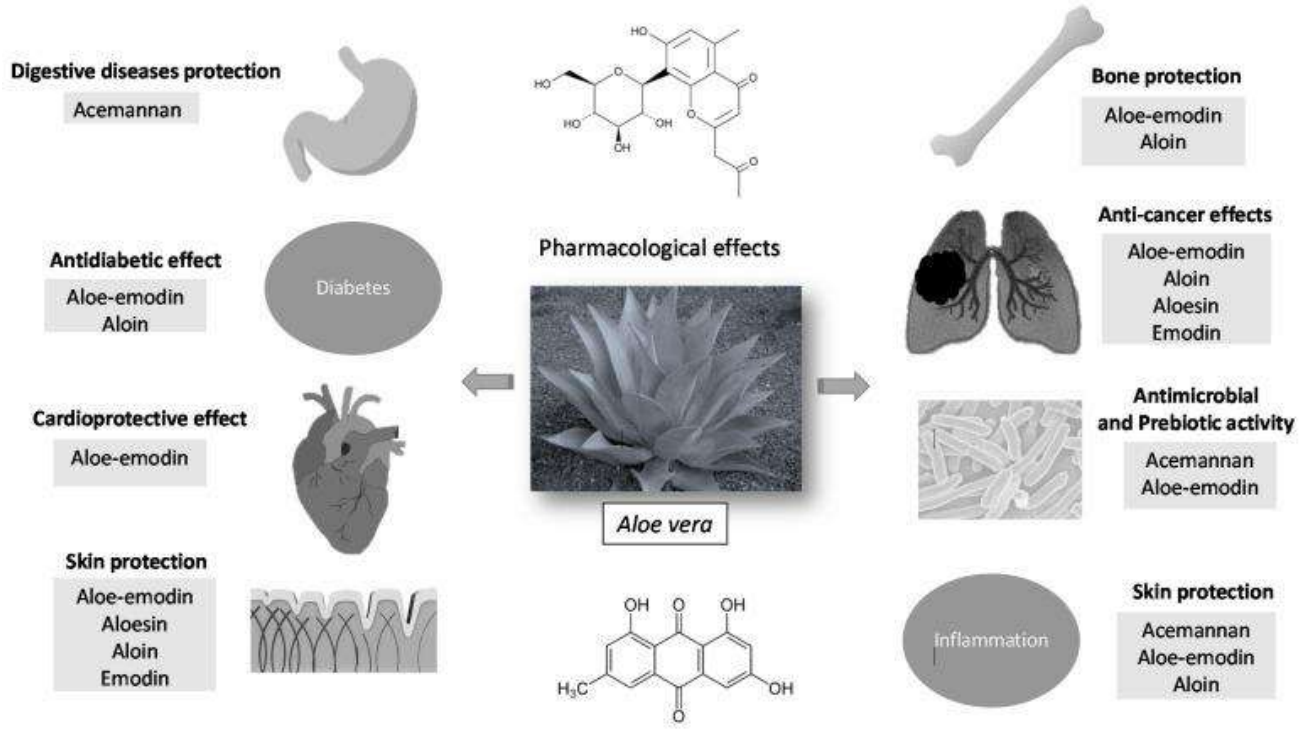


B. Anti-Inflammatory & Immunomodulatory Activity

- **Cytokine Downregulation:** *Aloe vera* gel extracts inhibit the expression of pro-inflammatory cytokines, including Tumor Necrosis Factor-alpha (TNF-α), Interleukin-6 (IL-6), and Interleukin-1 beta (IL-1β) (Abid, 2025).
- **Enzyme Inhibition:** Anthraquinones and chromones downregulate cyclooxygenase-2 (COX-2) and inducible nitric oxide synthase (iNOS), reducing prostaglandin PGE_2 and nitric oxide (NO) accumulation.

C. Antidiabetic & Metabolic Regulation

- **Glycemic Control:** Oral administration of gel fractions improves fasting blood glucose and glycosylated hemoglobin (HbA1c) levels by enhancing peripheral insulin sensitivity and upregulating GLUT-4 transporter translocation in adipose and skeletal muscle tissue.

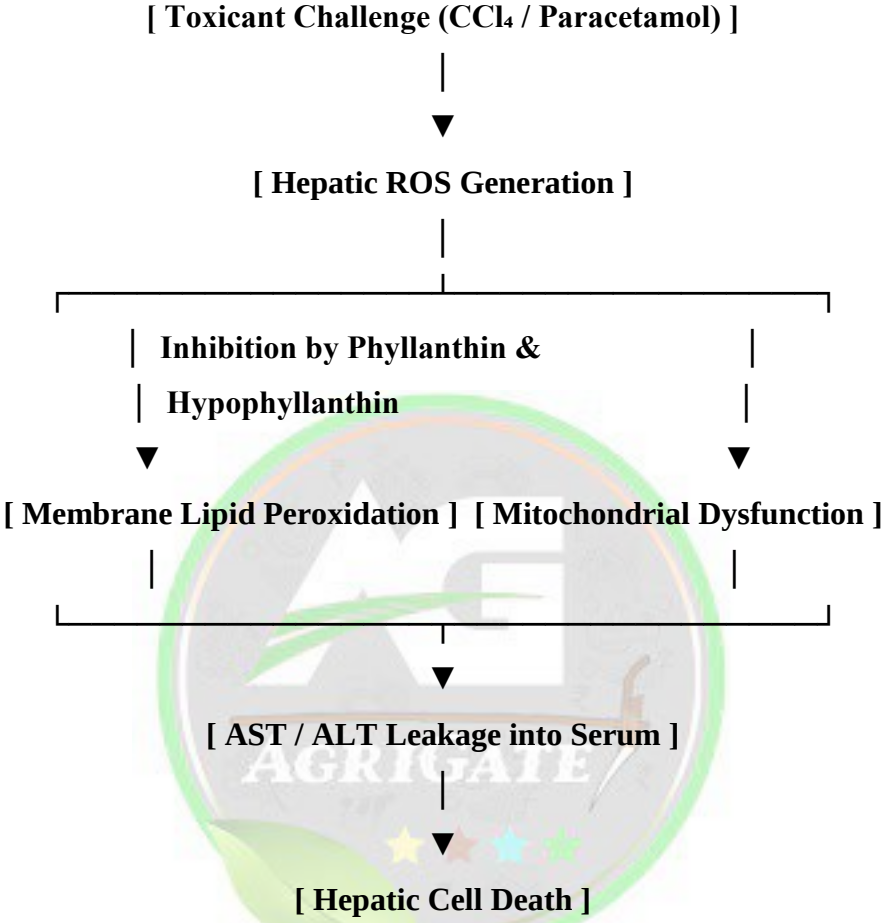


Pharmacological Spectrum of *Phyllanthus* Species

A. Hepatoprotective Activity

- **Membrane Stabilization:** Phyllanthin and hypophyllanthin preserve hepatocellular integrity under carbon tetrachloride (CCl4), paracetamol, or ethanol toxicity.

- **Enzyme Restoration:** Upregulates hepatic superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), and reduces serum aspartate aminotransferase (AST) and alanine aminotransferase (ALT) levels (Prananda et al., 2023).

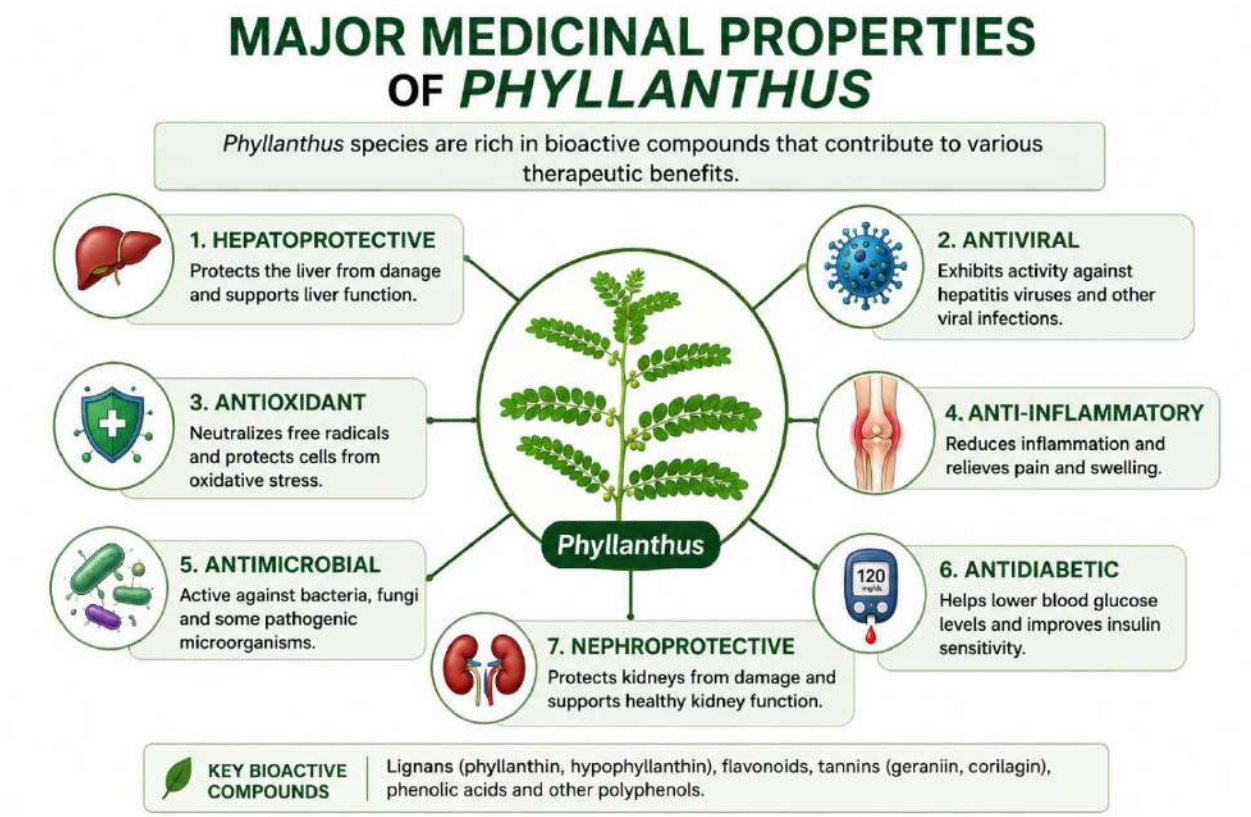


B. Antiurolithic (Anti-Kidney Stone) Properties

- **Inhibition of Crystal Formation:** *Phyllanthus niruri* and *P. amarus* aqueous extracts inhibit calcium oxalate (CaOx) crystal nucleation, growth, and aggregation in renal tubular fluid.
- **Morphological Modification:** Alters crystal shape from sharp monohydrate (COM) to less adherent dihydrate (COD) structures, facilitating their clearance via urine.

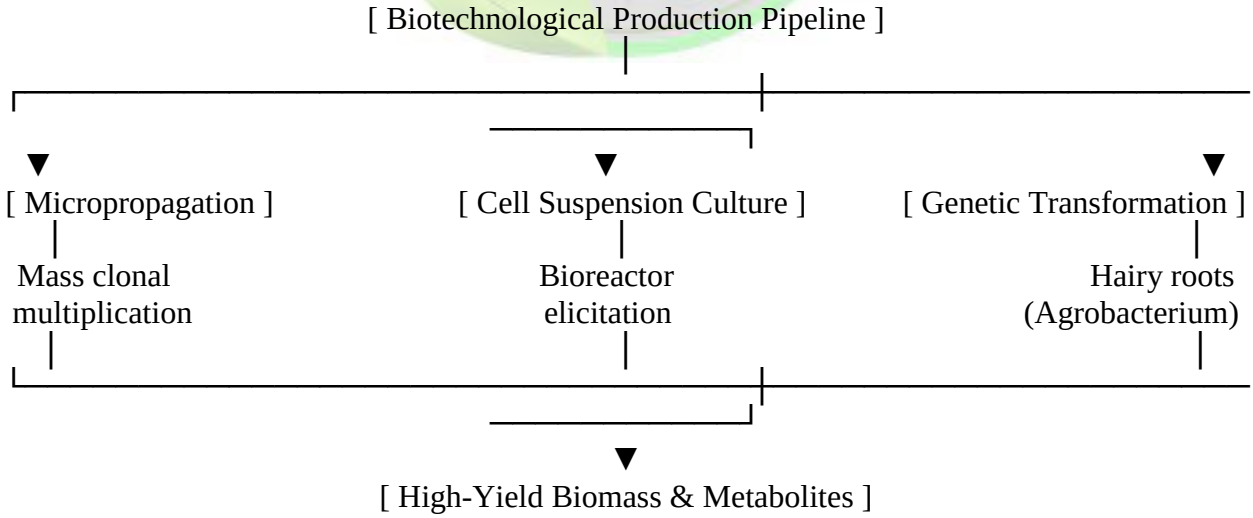
C. Antiviral Activity (Anti-HBV & Anti-HIV)

- **Viral Polymerase Inhibition:** Lignans and ellagitannins (corilagin, niranthin) inhibit Hepatitis B virus endogenously encoded DNA polymerase, blocking HBsAg and HBeAg expression.



Biotechnological Applications & Metabolic Engineering

To overcome field collection limitations—such as variable phytochemical yields, land constraints, and environmental fluctuations—plant biotechnology leverages *in vitro* propagation and bioengineering techniques.



Micropropagation & Clonal Propagation

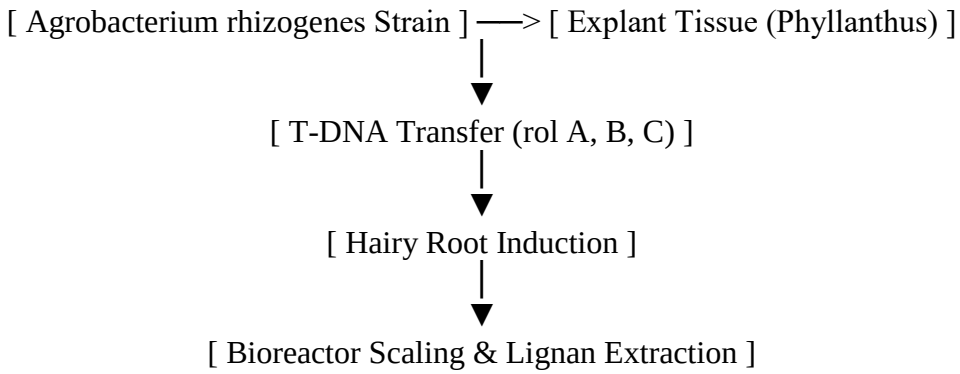
- **Aloe vera:** Micropropagation via shoot-tip / apical meristem culture on Murashige and Skoog (MS) medium supplemented with 6-Benzylaminopurine (BAP, 1.0–3.0 mg/L) and α-Naphthaleneacetic acid (NAA, 0.1–0.5 mg/L) enables rapid clonal multiplication free of soil-borne pathogen contamination.
- **Phyllanthus:** Nodal explants cultivated under controlled growth regulator regimes allow large-scale propagation of genetically uniform elite lines with verified high lignan or tannin contents.

Callus Culture & In Vitro Elicitation

- **Biotic Elicitors:** Application of yeast extract, chitosan, or methyl jasmonate (MeJA) to *Phyllanthus amarus* cell suspension cultures upregulates the expression of phenylalanine ammonia-lyase (PAL), increasing phyllanthin and hypophyllanthin accumulation.
- **Abiotic Elicitors:** Salicylic acid, UV-B irradiation, and controlled osmotic stress (e.g., polyethylene glycol) trigger defense pathways in *Aloe vera* cell cultures, boosting anthraquinone and aloesin biosynthesis.

Hairy Root Cultures & Genetic Transformation

- **Agrobacterium rhizogenes:** Infection of *Phyllanthus* explants using wild-type *A. rhizogenes* strains (e.g., A4, R1000) induces hairy root syndrome through transfer of the *Ri* plasmid *rol* genes (*rolA, rolB, rolC*).
- **Yield Optimization:** Hairy roots exhibit genetic stability, rapid hormone-autotrophic growth, and high secondary metabolite yields, providing a continuous platform for bioreactor-scale production of lignans and tannins.



Analytical Matrix: Phytochemical & Pharmacological Comparison

Parameter	Aloe vera (L.) Burm.f.	Phyllanthus amarus / niruri / emblica
Primary Plant Organ	Leaf pericyclic latex & inner parenchyma gel	Aerial shoots, leaves, stem, and fruit
Major Compound Classes	Anthraquinones, Chromones, Acemannan	Lignans, Hydrolyzable Tannins, Flavonoids
Key Bioactive Markers	Aloin A/B, Aloe-emodin, Aloesin, Acemannan	Phyllanthin, Hypophyllanthin, Corilagin, Geraniin
Biosynthetic Origin	Polyketide (anthraquinones) & Sugar Nucleotide pathways	Shikimate / Phenylpropanoid & Gallic acid pathways
Primary Target Diseases	Burns, wound healing, IBS, cutaneous inflammation	Hepatitis B, hepatic damage, urolithiasis, diabetes
Biotech Production	Shoot-tip micropropagation, gel stabilization	Hairy root cultures, elicitation, suspension cultures

Future Directions & Conclusion

The integration of secondary metabolite profiling with agricultural plant biotechnology offers promising opportunities for therapeutic development and commercial cropping systems.

Key development pathways include:

1. **Transcriptomic & Genomic Mapping:** Elucidating complete enzymatic gene clusters involved in the polyketide and phenylpropanoid pathways of *Aloe vera* and *Phyllanthus* to identify candidate genes for CRISPR/Cas9 editing.
2. **Bioreactor Scaling:** Transitioning cell suspension and hairy root cultures into large-scale airlift bioreactors for industrial synthesis of purified phyllanthin, aloe-emodin, and acemannan.

3. **Agronomic Standardization:** Developing transgenic or marker-assisted breeding lines resilient to abiotic stress while maintaining consistently high secondary metabolite titers.

References

Abid, A. (2025). The green healer: an updated review on the phytochemical profile and therapeutic potential of *Aloe vera*. *Frontiers in Nutrition*, *12*, 1689700.

Nawfetrias, W., Devy, L., Esyanti, R. R., & Faizal, A. (2024). *Phyllanthus* lignans: A review of biological activity and elicitation. *Horticulturae*, *10*(2), 195. https://doi.org/10.3390/horticulturae10020195

Prananda, A. T., Dalimunthe, A., Harahap, U., Simanjuntak, Y., Peronika, E., Karosekali, N. E., Hasibuan, P. A. Z., Syahputra, R. A., Situmorang, P. C., & Nurkolis, F. (2023). *Phyllanthus emblica*: a comprehensive review of its phytochemical composition and pharmacological properties. *Frontiers in Pharmacology*, *14*, 1288618. https://doi.org/10.3389/fphar.2023.1288618

Radha, M. H., & Laxmipriya, N. P. (2015). Evaluation of biological properties and clinical effectiveness of *Aloe vera*: A systematic review. *Journal of Traditional and Complementary Medicine*, *5*(1), 21–26. https://doi.org/10.1016/j.jtcme.2014.10.006

Sánchez, M., González-Burgos, E., Iglesias, I., & Gómez-Serranillos, M. P. (2020). Pharmacological update properties of *Aloe vera* and its major active constituents. *Molecules*, *25*(6), 1324. https://doi.org/10.3390/molecules25061324

Volume: 06 Issue No: 09

LIVING SOIL AND NATURAL FARMING: RESTORING SOIL ORGANIC MATTER FOR SUSTAINABLE AGRICULTURE

Article ID: AG-V06-I09-114

Ritik Kumar Maurya[1*] and Bhaskar Shastri[2]

Phd Scholar [1]Department of Agronomy, College of Agriculture, G.B. Pant University of Agriculture and Technology, Pantnagar, India

Phd Scholar [2]Department of Entomology, College of Agriculture, G.B. Pant University of Agriculture and Technology, Pantnagar, India

*Corresponding Author: Ritik Kumar Maurya

Abstract

Sustaining soil health has emerged as one of the greatest challenges in modern agriculture due to continuous intensive cultivation, excessive use of chemical fertilizers, residue burning, and declining organic matter levels. In many farming systems, soil has gradually lost its biological activity, resulting in reduced nutrient-use efficiency, lower water-holding capacity, declining productivity, and increasing vulnerability to climatic stress. Under these circumstances, natural farming has gained significant attention as an ecologically sustainable approach for restoring soil vitality and improving long-term agricultural resilience. The present article discusses the importance of living soil and the critical role of soil organic matter in maintaining sustainable crop production. Soil is increasingly recognized as a dynamic living ecosystem containing diverse microorganisms that regulate nutrient cycling, organic matter decomposition, and plant growth. The article highlights how practices associated with natural farming, including residue recycling, mulching, Jeevamrit application, diversified cropping systems, and reduced soil disturbance, contribute to the restoration of microbial activity and improvement of soil structure. Particular emphasis has been placed on the role of soil organic matter in enhancing water retention, nutrient availability, carbon sequestration, and climate resilience. The article further discusses the practical challenges associated with transitioning toward natural farming, especially during the initial years of adoption. It concludes that restoring soil biological activity through integrated ecological management is essential for achieving sustainable agriculture

under changing climatic conditions. Long-term soil stewardship, supported by scientific research and farmer participation, will play a crucial role in ensuring future food security, environmental sustainability, and resilient farming systems.

Key word; Natural farming, living soil, soil organic matter, soil health, microbial activity, sustainable agriculture, carbon sequestration, climate resilience, residue recycling, Jeevamrit, soil biology, ecological farming, nutrient cycling, regenerative agriculture, soil fertility.

Introduction

Agriculture in India has witnessed remarkable transformation during the past five decades. The introduction of high-yielding varieties, chemical fertilizers, pesticides, and irrigation technologies significantly increased food grain production and helped the country achieve food security. However, continuous intensification of farming systems has also created several long-term challenges related to soil health, environmental sustainability, and farm profitability. In many agricultural regions, farmers are now facing declining soil fertility, rising input costs, reduced water-use efficiency, and increasing vulnerability to climate stress.

Among these challenges, the gradual deterioration of soil health has emerged as one of the most serious concerns affecting sustainable crop production. Farmers often observe that despite applying higher quantities of fertilizers every year, crop response is not improving proportionally. Soil has become harder, irrigation frequency has increased, and productivity in many fields has either stagnated or started declining. Such conditions indicate that agricultural soils are slowly losing their biological strength.

In recent years, natural farming has gained considerable attention as an alternative approach for restoring soil health and reducing dependence on external chemical inputs. The central principle of natural farming is based on the idea that soil should not be treated merely as a physical support for plants, but as a living ecosystem containing billions of microorganisms that continuously regulate nutrient cycling and plant growth. Restoring soil organic matter and microbial activity therefore becomes essential for long-term agricultural sustainability.

2. Soil: A Living System

Healthy soil is one of the most biologically active natural systems on earth. A single gram of fertile soil may contain millions of bacteria, fungi, algae, protozoa, and other microorganisms. These organisms play an important role in decomposing organic residues, recycling nutrients, improving soil structure, and maintaining ecological balance within the rhizosphere.

In traditional farming systems, continuous recycling of organic biomass maintains soil biological activity naturally. Crop residues, animal manure, leaf litter, and other organic materials were regularly incorporated into the soil. As a result, soils remained porous, fertile, and capable of sustaining crop productivity for long periods.

However, intensive cultivation practices gradually disturbed this balance. Excessive tillage, residue burning, monocropping, and indiscriminate use of chemical fertilizers reduced the organic carbon content of soils in many agricultural regions. The decline in soil organic matter directly affects microbial diversity and weakens the natural nutrient cycling process. Consequently, soils become increasingly dependent on synthetic inputs for maintaining productivity.

Natural farming emphasizes rebuilding this lost biological foundation through ecological management practices. Instead of feeding the crop directly through chemical fertilizers, the focus is placed on feeding the soil biology that ultimately supports plant growth.

3. Importance of Soil Organic Matter

Soil organic matter is often referred to as the "life force" of agricultural soil. It consists of decomposed plant and animal residues, microbial biomass, and humus formed through biological decomposition. Although present in relatively small quantities, organic matter exerts enormous influence on soil productivity and environmental sustainability.

One of the most important functions of soil organic matter is improving soil structure. Organic substances bind soil particles together and form stable aggregates, which improve soil porosity and aeration. Well-aggregated soil allows better root penetration and creates favourable conditions for microbial growth. In contrast, soils deficient in organic matter often become compact and hard, restricting root development and reducing water infiltration.

Organic matter also plays a critical role in water retention. Soils rich in organic carbon can absorb and retain significantly higher amounts of moisture compared to degraded soils. This characteristic becomes extremely important under rainfed conditions and during prolonged dry spells. Improved moisture retention not only supports crop growth but also enhances resilience against drought and climatic variability.

Another important benefit of organic matter is nutrient regulation. Organic residues act as slow-release reservoirs of essential nutrients such as nitrogen, phosphorus, sulfur, and micronutrients. Microorganisms gradually decompose these materials and release nutrients in plant-

available forms. This process improves nutrient-use efficiency and minimizes losses through leaching or volatilization.

4. Natural Farming and Soil Biological Activity

Natural farming systems aim to reactivate soil biology using locally available organic resources. Preparations such as Jeevamrit, Beejamrit, Ghanjeevamrit, and mulching materials are intended to stimulate beneficial microbial populations and enhance biological processes within the soil. Among these, Jeevamrit has received considerable attention due to its role in increasing microbial activity. Prepared using cow dung, cow urine, pulse flour, jaggery, and soil, Jeevamrit provides a favourable environment for the multiplication of beneficial microorganisms. When applied regularly, it may improve microbial diversity and support nutrient mineralization processes.

Mulching is another important practice in natural farming. Crop residues or organic materials spread over the soil surface help conserve moisture, moderate soil temperature, suppress weed growth, and gradually contribute to organic matter accumulation. Mulching also protects the soil surface from erosion caused by heavy rainfall and reduces evaporation losses during summer months. Natural farming practices often encourage minimum soil disturbance and diversified cropping systems. Reduced tillage helps preserve soil structure and microbial habitats, while crop diversification improves ecological stability within farming systems. Inclusion of legumes and cover crops further contributes to nitrogen fixation and biomass addition.

5. Soil Health and Climate Resilience

Climate change has introduced new uncertainties into agricultural production systems. Rising temperatures, irregular rainfall patterns, droughts, and extreme weather events are increasingly affecting crop productivity across many regions of India. Under such conditions, healthy soil becomes one of the strongest defenses against climatic stress. Soils rich in organic matter possess greater buffering capacity against environmental fluctuations. Improved water-holding capacity helps crops tolerate temporary drought conditions, while better soil aggregation enhances infiltration during heavy rainfall events. Biological activity within healthy soils also supports stronger root systems and improved nutrient uptake under stress conditions.

An additional environmental advantage of organic matter restoration is carbon sequestration. Agricultural soils act as important reservoirs of terrestrial carbon. By increasing soil organic carbon levels, sustainable farming systems can help capture atmospheric carbon dioxide and reduce

greenhouse gas accumulation. Thus, improving soil health contributes not only to agricultural sustainability but also to climate change mitigation.

5. The Way Forward

The future of sustainable agriculture will depend largely on restoring the biological health of soils. Excessive dependence on external chemical inputs is proving economically and environmentally unsustainable in many farming systems. Natural farming offers an opportunity to rebuild ecological balance while reducing production costs and improving long-term resilience. However, sustainable agriculture should not be viewed as a conflict between traditional and modern science. Instead, future farming systems will likely integrate ecological principles with scientific innovations. Precision nutrient management, microbial technologies, residue recycling, integrated farming systems, and conservation agriculture can collectively contribute toward healthier and more productive soils.

Agricultural universities, research institutions, and extension agencies have an important role in promoting scientific understanding of soil biology and sustainable land management. Farmers also need greater awareness regarding the importance of organic matter conservation and responsible soil stewardship.

Conclusion

Soil is not merely a medium for crop cultivation; it is a living and dynamic ecosystem that sustains agricultural productivity and environmental health. The declining status of soil organic matter in many farming regions has emerged as a serious threat to sustainable agriculture. Restoring soil biological activity through natural farming and ecological soil management practices therefore becomes increasingly important. Practices such as residue recycling, mulching, organic matter incorporation, microbial formulations, and diversified cropping systems can gradually improve soil structure, nutrient cycling, water retention, and climatic resilience. Although the transition toward biologically sustainable farming systems requires patience and scientific management, the long-term benefits for soil health, farmer livelihoods, and environmental sustainability are substantial.

The future of agriculture ultimately depends on how effectively we conserve and regenerate the living soil beneath our feet. Healthy soils support healthy crops, and healthy crops form the foundation of food security and sustainable rural development

Volume: 06 Issue No: 09

ADVANCED ORGANIC TOMATO FARMING: A COMPREHENSIVE GUIDE TO YIELD OPTIMIZATION AND ECOLOGICAL CROP PROTECTION

Article ID: AG-VO6-I09-115

[1]Manju Netwal, [1]Tarun Kumar Jatwa*, [2]B. L. Jat, [1]Jitendra Kumar Gupta, [1]R. C. Asiwal and [1]Lalaram Balai

[1]Assistant Professor, COA, Lalsot, SKNAU, Jobner, Jaipur 303329, India

[2]Professor, COA, Lalsot, SKNAU, Jobner, Jaipur 303329, India

Corresponding Author**:** Tarun Kumar Jatwa

Introduction

Tomato is one of the most important fruit crops in the world, ranking second only to the potato in many countries. It belongs to the Solanaceae family and the genus *Lycopersicon*. While *Lycopersicon* species are native to Ecuador, Peru, and the Galapagos Islands, historical evidence suggests that tomatoes were first domesticated in Mexico. Today, the tomato (*Solanum lycopersicum* L.) is one of the world most popular and widely cultivated vegetable crops. It ranks first in its overall dietary contribution because it is consumed in such large quantities. Tomatoes are cultivated globally, with major producers including China, the USA, Turkey, Italy, Egypt, India, Spain, Brazil, Iran, and Mexico. In India, tomatoes are a staple ingredient enjoyed by people of all economic backgrounds. Tomato stew is a celebrated dish, particularly on Sundays and during festive occasions. Beyond stews, tomatoes are eaten raw, cooked, or processed into products such as soup, juice, sauce, ketchup, puree, paste, and powder.



The fruit is an affordable and rich source of vital nutrients. As a globally important crop with year-round demand, tomatoes are grown everywhere from small home gardens to massive commercial farms. Beyond being eaten fresh in salads, they are a key ingredient in soups, chutneys, sauces, and juices. Nutritionally, every 100 grams of tomato provides about 0.9 grams of protein, 0.8 grams of fibre, 3.6 grams of carbohydrates, and 20–25 calories. They are also packed with vitamins A, C, B1, and B2, and serve as an excellent source of health-boosting antioxidants and wide range of minerals, including potassium, calcium, sodium, magnesium, phosphorus, boron, manganese, zinc, copper, and iron. It also provides organic acids such as citric, malic, and acetic acids which are beneficial to health. Furthermore, tomatoes are an excellent source of lycopene, a powerful antioxidant linked to a reduced risk of heart disease, prostate cancer, and various other forms of cancer. The tomato plant can reach heights of 1 to 3 metres (3 to 10 feet). It features a weak stem that typically sprawls along the ground or climbs over adjacent vegetation. Although it behaves as a perennial in its native habitat, it is frequently grown as an annual outdoors in temperate climates.



As of the latest **2024–2025 Third Advance Estimates** released by the Ministry of Agriculture & Farmers Welfare, India's overall tomato production is projected to hit **19.47 million tonnes**.

Table 1. Comparison of overall tomato and organic tomato production

Metric	Overall Indian Tomato Cultivation	Organic Tomato Estimates & Dynamics
Total Area	**0.84 million hectares (Mha)**	**25,000 hectares** (Estimated share of dedicated organic acreage)
Total Production	**19.468 million tonnes** (Latest 2024–25 baseline)	**500,000 metric tonnes** (Primarily localized or export-oriented)

Average Productivity (Yield)	**25.3 metric tonnes per hectare (MT/ha)**	**22 MT/ha** (Typically 15-20% lower than intensive conventional farming initially)
Growth Trends (CAGR)	Area: **+3.25%** | Production: **+5.90%** | Yield: **+2.56%**	Yield grows over time as soil organic matter builds up and bio-inputs stabilize.

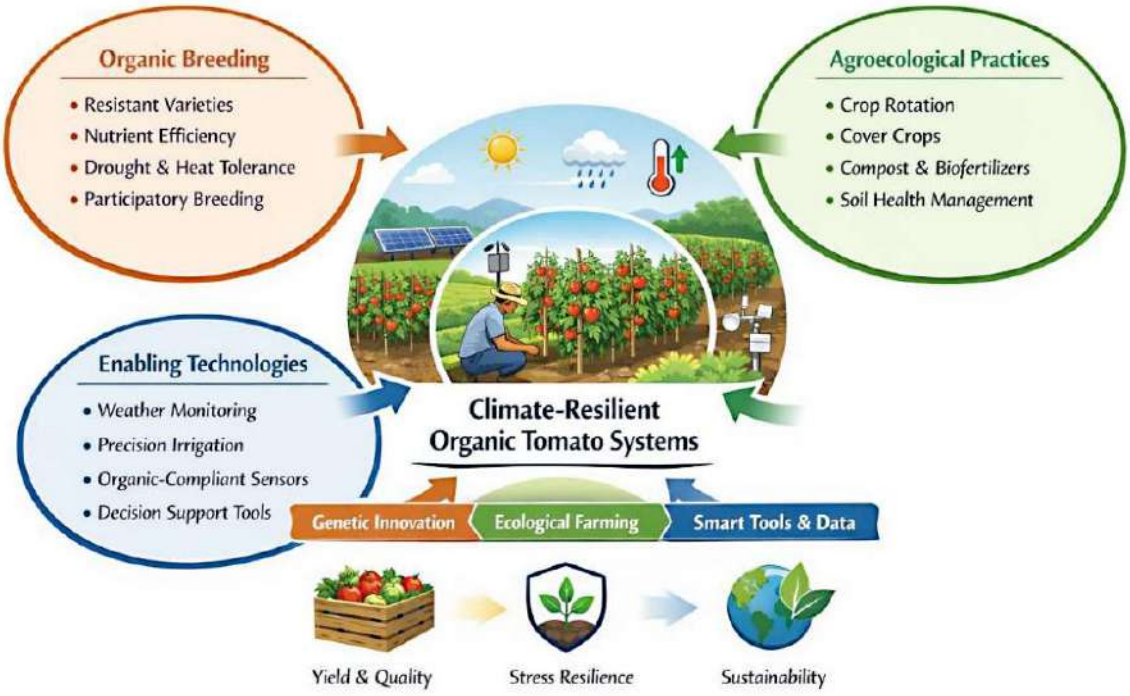
Table 2. Area production and productivity state wise

State / UT	Area ('000 Ha)	Production ('000 MT)	Avg Productivity (MT/Ha)	Est. Organic Tomato Area ('000 Ha)	Est. Organic Production ('000 MT)
Madhya Pradesh	148.50	3,120.40	21.01	**4.45**	**84.60**
Andhra Pradesh	76.00	1,453.00	19.12	**2.28**	**38.50**
Tamil Nadu	44.90	1,414.01	31.49	**1.35**	**33.90**
Karnataka	51.20	1,756.70	34.31	**1.54**	**44.80**
Gujarat	29.00	650.00	22.41	**0.87**	**17.20**
Rajasthan	20.14	323.44	16.06	**0.60**	**8.10**
Telangana	18.93	509.33	26.91	**0.57**	**12.20**
Tripura	2.12	62.08	29.28	**0.21**	**5.30**
Sikkim	0.44	4.57	10.39	**0.44**	**4.57**

The Paradigm Shift in High-Yield Organic Tomato Culture

The global market for organic vegetable cultivation and produce has fundamentally outgrown its status as a niche consumer trend, solidifying into a high-stakes, commercial discipline. While growing organic tomatoes (*Solanum lycopersicum*) offers the highest financial rewards, it is also the most difficult crop for modern farmers to manage. In the past, switching to organic farming meant accepting smaller harvests because growers could not easily control pests, diseases, and soil nutrient loss. Today, that compromise is over. Modern organic farms no longer just defend against problems; they use advanced agricultural science to produce yields that match or beat traditional chemical farming.

To grow high yields of top-quality organic tomatoes, farmers must stop simply replacing chemical inputs with organic ones. Just swapping chemical fertilizers for manure or using copper sprays instead of chemical fungicides is no longer enough to run a profitable business. Instead, modern commercial growers must use precise, science-backed steps at every stage of the plant's life. This means managing the root zone using beneficial microbes to control how nutrients move, and turning the farm into a self-defending ecosystem rather than a sterile field. This guide provides a practical blueprint for commercial growers. By combining soil science, natural plant



immunity boosters, and beneficial insects, we move beyond basic farming rules. The following sections outline the exact steps needed to improve plant growth, build natural barriers against local diseases, and protect your tomato crop from pests—all while keeping your organic certification and maximizing your profits. Because demand is constant, growing tomatoes to meet market needs is highly profitable. By adopting modern organic farming techniques, growers can achieve high yields while protecting consumer health

Climate for Organic Cultivation of Tomato

Tomato is a warm-season crop of tropical origin, though it is cultivated globally across both summer and winter cropping cycles. While optimal vegetative development and photosynthetic efficiency occur within a high-temperature range of 34–39°C, extreme thermal

stress exacerbates the vapor pressure deficit (VPD). Under hot, arid conditions, elevated evapotranspiration rates induce a state of physiological drought, triggering abscisic acid (ABA) synthesis that leads to premature fruit abortion and flower drop. Furthermore, ambient temperature and solar radiation play a critical role in determining fruit quality, specifically dictating the accumulation of soluble solids and organic acids. Lycopene biosynthesis, the primary carotenoid responsible for the characteristic deep red pigmentation is highly temperature-dependent, occurring optimally between 18°C and 26°C, but inhibited at temperatures exceeding 30°C. Consequently, winter-harvested fruits often achieve superior organoleptic profiles, featuring high total soluble solids (TSS, measured in °Brix) and intense coloration. Conversely, high summer temperatures restrict lycopene accumulation while altering the titratable acidity, resulting in pale, highly acidic fruits dominated by citric and malic acids.

Selection of Land:

Well-drained loamy soil is suitable for tomato cultivation. Light soil is suitable for early crops, whereas clay loam and loam soils are better for obtaining higher yields. Tomato performs well in soil having a pH of 6–7.

Field Preparation:

The first ploughing should be done with a mould-board plough. After that, 3–4 ploughings should be done with a country plough or cultivator. After each ploughing, planking should be done so that the soil becomes friable and level.

Selection of Varieties:

For successful organic tomato cultivation in India, selecting the correct variety determines your input costs, disease management workload, and final market premium. Organic farming strictly restricts synthetic chemical inputs, making **genetic disease resistance, local adaptability, and nutrient efficiency** the primary criteria for variety selection. When choosing a variety, farmers must pick between two distinct categories based on their business model and seed management strategy:

S.No	Open-Pollinated (Improved / Desi Varieties)	Hybrid (F1) Varieties
Seed Saving	**Highly suitable.** Seeds can be saved and reused for the next season.	**Not suitable.** Fresh seeds must be purchased every season.

Nutrient Demand	**Low to Moderate.** Thrives easily on organic compost and farmyard manure (FYM).	**High.** Requires heavy, continuous organic feeding to reach yield potential.
Disease Tolerance	**Often possess strong, natural** evolutionary resistance **to local pests.**	Feature **scientifically bred resistance** against specific multi-viruses.
Yield & Uniformity	**Moderate yields with variable fruit sizes.**	Very high yields with highly uniform fruit size and shape.

Some improved and hybrid varieties are as follows:

Premium Open-Pollinated (OP) & Desi Varieties:

- **Pusa Ruby (IARI):** Early-maturing, highly adaptable, and a reliable **all-season performer**. It features uniform, medium-sized, slightly flattened fruits that grow well even under lower-fertility organic regimes.
- **Arka Vikas (IIHR):** Open-pollinated variety known for **excellent heat tolerance**, making it a staple for summer cropping. Fruits are firm, medium-large (70–80g), and offer dependable table-purpose quality.
- **Pusa Sheetal (ICAR):** This variety is highly recommended for organic farming due to its **excellent accumulation of Vitamin C, sugars, and antioxidants** under organic management. It exhibits an exceptional shelf-life at room temperature, easing logistics for organic supply chains.
- **Arka Saurabh:** A semi-determinate variety producing deep, firm, attractive fruits with a **high keeping quality**, making it easier to transport organically grown produce without bruising.
- **Arka Meghali:** Specifically bred for **rain-fed (monsoon) environments**. It possesses t

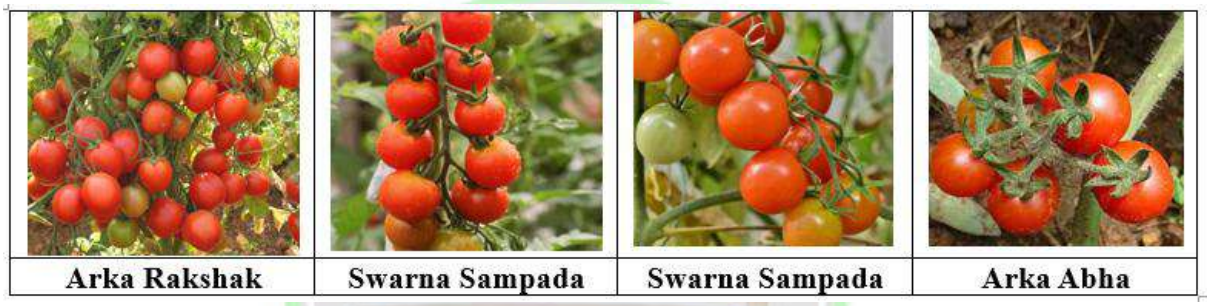


Pusa Ruby (IARI) | Arka Vikas (IIHR) | Pusa Sheetal (ICAR) | Arka Saurabh | Arka Meghali

r flesh, which naturally resists fruit cracking caused by moisture fluctuations

Disease-Resistant Hybrids (F1):

- **Arka Rakshak:** A triple-disease-resistant powerhouse bred by IIHR. It provides genetic resistance to **Tomato Leaf Curl Virus (ToLCV), Bacterial Wilt, and Early Blight**. This built-in resistance dramatically lowers the need for organic botanical sprays or copper-based bio-pesticides.
- **Swarna Sampada:** Highly recommended for North, East, and Central India. It offers robust **bacterial wilt and early blight resistance**, producing massive yields (up to 400 quintals/acre) under optimal organic field management.
- **Pusa Hybrid 6:** Highly tolerant to the devastating **leaf curl virus and fruit borers**. It delivers high yields of attractive 90–100g fruits that command premium pricing in organic mandis



Arka Rakshak	Swarna Sampada	Swarna Sampada	Arka Abha

Selection Criteria Based on Regional Agro-Climatic Risks

- **Bacterial Wilt Prone Zones (e.g., Kerala, Coastal Karnataka and North-East):** Prioritise varieties like **Arka Abha**, **Swarna Sampada**, or **Sakthi**. Standard varieties will rot quickly in wilt-infected soils.
- **High Temperature / Arid Belts (e.g., Rajasthan, Central MP and Gujarat):** Choose heat-tolerant types like **Arka Vikas**, **Marutham**, or **Navbahar**. These maintain good fruit setting even when temperatures climb.
- **Heavy Rainfall / Monsoon Cultivation (Kharif):** Lean toward **Arka Meghali** or **Arka Abha**. Their genetic traits prevent water-logged root rot and skin splitting during heavy downpours.

Sowing Timeline and Transplanting Dynamics:

Tomato cultivation relies on an indirect establishment method wherein seeds are initially germinated in a controlled nursery environment rather than via direct field sowing. Seedlings are

managed within the nursery beds for a duration of 4–5 weeks, or until they attain an optimal morphological height of approximately 10–15 cm, at which stage they are transplanted into the primary field. The synchronized seasonal sowing schedule is categorized below:

- **Kharif (Monsoon) Crop**: Nursery sowing is initiated on raised beds during June.
- **Summer Crop**: Seed oviposition in nursery beds is executed between December and January.
- **Rabi (winter) Crop**: Seedling propagation is conducted in nursery beds during September.

Seed Rate:



Under organic production paradigms, open-pollinated improved cultivars demand a seeding density of approximately 500–600 g ha^{-1}. Conversely, due to high germination vigor and distinct canopy architecture, F1 hybrid varieties require a minimized seed rate of 200–250 g ha^{-1} to achieve optimum plant populations.

Nursery Bed Preparation

Nursery beds must be prepared with a standard width of 1.0 m and an elevated height of approximately 15 cm (6 inches), with variable lengths adjusted to specific seedling volume requirements. To ensure adequate nutrient availability and physical soil properties for early root development, a standardized bed layout (3.0 m × 1.0 m × 25–38 cm) is supplemented with 20–25 kg of fully humified farmyard manure (FYM). Precise levelling of the bed surface is critical to prevent waterlogging and subsequent root-zone hypoxia.



Soil Solarization and Phytosanitation

Soil solarization is utilized as a non-chemical, hydrothermal disinfection methodology to suppress soil-borne pests and pathogens. During peak summer periods, the substrate is mulched with transparent polyethylene sheets to capture solar radiation via the greenhouse effect, thereby driving up soil temperatures.

Empirical observations indicate that solarization elevates soil temperatures by 10–12°C or greater at a depth of 5 cm relative to non-solarized controls. Sustaining this thermal regime for

a continuous 40-day duration effectively inactivates and destroys the resting spores and propagules of economically damaging soil-borne phytopathogens, including *Fusarium* spp., *Rhizoctonia* spp., and *Sclerotium* spp.

Seed treatment:

For certified organic tomato production, seeds undergo a sequential pre-sowing protective treatment. Initial seed priming is conducted using bioactive organic solutions such as diluted cow urine or neem (*Azadirachta indica*) oil formulations to provide early antimicrobial defense. Subsequently, 2–3 hours prior to sowing, the seed coat is inoculated with beneficial microbial agents, including the biocontrol fungus *Trichoderma* spp., or biofertilizers such as *Rhizobium* spp. and Phosphate Solubilizing Bacteria (PSB), to enhance seedling vigor, nutrient mobilization, and systemic resistance.

Nursery Geometry and Seed Deposition

Seeds should be precisely sown at an intra-row and inter-row spacing of approximately 5 cm × 2 cm, adhering to a uniform seeding depth of 0.5–1.0 cm. To optimize seed-to-soil contact and facilitate optimal microclimate conditions, rows are backfilled with a fine mixture of sterilized soil and humified farmyard manure (FYM). Post-sowing irrigation must be applied immediately, followed by mulching the beds with dry grass and twigs to minimize evaporative water loss and conserve substrate moisture. This mulch layer must be systematically removed upon reaching approximately 50% seedling emergence to prevent etiolation and mitigate microclimatic conditions conducive to insect vectors and fungal pathogens.

Seedling Cultivation and its Management:

Irrigation frequencies must be dynamically adjusted (once or twice daily) based on ambient agrometeorological conditions. High seeding densities and excessive irrigation must be strictly avoided to mitigate the incidence of damping-off disease, primarily incited by *Pythium* and *Rhizoctonia* species. Upon seedlings reaching a phenotypic height of 8–10 cm, a foliar application of *Panchagavya* solution (a traditional organic bio-stimulant) should be administered to enhance chlorophyll synthesis and vigor. Weed management requires timely manual weeding paired with light intercultural operations (hoeing) to alleviate soil compaction. At 4–6 weeks post-sowing, when seedlings reach a height of 10–15 cm, irrigation is deliberately withheld to initiate physiological hardening. On the scheduled day of transplanting, nursery beds must undergo saturating irrigation 1–2 hours prior to extraction; this decreases soil shear strength,

facilitating seamless uprooting while preserving root system architecture. Transplanting should be preferentially executed during the evening to reduce transplant shock, followed by immediate field irrigation and a daily irrigation regimen until complete seedling establishment is achieved.

Seedling Ontogeny in Plug Trays (Pro-Trays)

For modernized, containerized seedling production, rigid plastic plug trays featuring 3-inch cell dimensions are utilized. The cells are packed with one of two standardized, lightweight growing media formulations:

1. **Media Formulation I:** Well-decomposed farmyard manure (or vermicompost) and cocopeat blended in a 1:1 (v/v) ratio.
2. **Media Formulation II:** Cocopeat, vermicompost, and vermiculite blended in a 3:1:1 (v/v/v) ratio.

A single pre-treated seed is deposited per cell. Utilizing these inert, porous substrates effectively isolates seedlings from field-borne soil pathogens, promoting robust root development, reducing post-transplant mortality rates, and ultimately driving precocious flowering and elevated cumulative yields.



Prophylactic Plant Protection and Hardening Protocols

- **Entomological Management:** To suppress infestation by phloem-feeding sucking pests, particularly whiteflies (*Bemisia tabaci*), 15-day-old seedlings should be treated with a foliar spray of potassium-based neem soap formulated at a concentration of 7 g L^{-1}.
- **Physiological Hardening:** Seedlings must be hardened by marginally restricting moisture availability 2–3 days prior to field transfer and exposing them to direct, ambient solar radiation 1–2 days before transplanting. A thorough irrigation must be executed approximately 12 hours prior to field extraction. Ideal seedling ideotypes for field transplanting are characterized by a 4-week chronological age, a robust stem caliper, and 4–5 true leaves.
- **Biocontrol and Antimicrobial Root Dipping:** For comprehensive protection against vascular wilt pathogens, seedling root systems should be subjected to pre-transplant protective dips:

- **Biological Control:** Root immersion in a liquid formulation of *Pseudomonas fluorescens* at a concentration of 10 g L^{-1}.
- **Botanical Prophylaxis:** Root immersion for 15–30 minutes in an aqueous solution of asafoetida (*Ferula foetida*), prepared by dissolving 100 g of the oleo-gum-resin in 5 L of water. This specialized treatment acts as a defensive barrier against soil-borne wilt-inducing phytopathogens prior to final field settlement.

Soil Fertility Enrichment and Pre-Plant Nutrition

Implementing crop rotation strategies with leguminous or pod-bearing cultivars enhances the nitrogen status of the soil via symbiotic nitrogen fixation. For organic production of *Solanum lycopersicum*, basal fertilizer application during the final tillage operations requires either 40 t ha^{-1} of fully humified farmyard manure (FYM) or 8–10 t ha^{-1} of premium vermicompost. To establish early biological suppression of soil-borne pathogens, the organic manure should be enriched with the biocontrol agent *Trichoderma* spp. at a concentration of 500 g t^{-1}.

Following field preparation, a system of raised beds and furrows must be engineered at 1.0 m center-to-center intervals. Additionally, de-oiled neem (*Azadirachta indica*) cake should be incorporated at a rate of 250 kg ha^{-1} during bed preparation, with a sequential split-application administered seven weeks post-transplanting to serve as a slow-release nutrient source and an organic nematicide.

Spatial Geometry and Field Architecture

To optimize canopy microclimates, enhance atmospheric circulation, and attenuate the rapid transmission of polycyclic foliar pathogens, spatial geometry must be tailored to cultivar growth habits.

- **Dwarf (Determinate) Cultivars:** A spacing regimen of 60 cm × 45 cm is recommended.
- **Tall (Indeterminate) Cultivars:** A spacing matrix of 90 cm × 30 cm should be maintained to accommodate vertical growth.
- **Protected Cultivations (Polyhouses):** An inter-row spacing of 70–90 cm is maintained to optimize light interception and facilitate worker ergonomics.

Hydrological Regimes and Water-Use Management

The moisture-sensitive growth stages of tomato are highly pronounced immediately post-transplanting (initial establishment), during anthesis (flowering), and throughout ontogenetic fruit development. Precision water delivery via furrow or drip irrigation systems is critical to

sustaining physiological vigor. Under arid agrometeorological conditions, irrigation should be scheduled at 3–4 day intervals during the initial post-transplanting phase, subsequently transitioning to a 5–7 day irrigation frequency until crop physiological maturity.

Canopy Pruning and Structural Staking



Indeterminate (tall) cultivars exhibit extensive vegetative elongation, necessitating structural support. Plants are trained vertically using high-tensile twine or trellis ropes. Canopy architecture is managed by maintaining a single dominant main stem, which requires the systematic excision of lateral axillary shoots (suckering) at regular intervals.

Structural staking effectively prevents direct contact between developing fruits and the soil-water interface, drastically reducing the incidence of soil-borne fruit rots. Furthermore, vertical training increases planting density per unit area, optimizing land equivalent ratios and driving higher cumulative yields.

Intercultural Weed Management and Mulching Protocols



Manual weeding regimes serve the dual purpose of eliminating weed-crop competition and facilitating soil aeration through light intercultural tillage. Under organic paradigms, primary hand-weeding operations are synchronized at the third and seventh weeks post-transplanting, with supplementary interventions executed dynamically based on weed seed bank expression. Integrated weed management (IWM) should incorporate diversified crop rotations, cover crops, and protective mulching. Utilizing organic mulches composed of clean crop residues, straw, or biomass retrieved during hoeing operations effectively suppresses weed seed germination, buffers soil temperatures, and curtails evaporative water loss.

Pest and Disease Management

Tomato crops are highly susceptible to an array of phytophagous insect pests and virulent pathogenic microflora, which induce severe quantitative and qualitative yield losses.

Comprehensive pest and disease management under organic production paradigms relies heavily on proactive, non-chemical, and biological interventions. The primary biotic threats are classified as follows:

Arthropod and Nematode Pests:

- Cutworms (*Agrotis* spp.), fruit borers (*Helicoverpa armigera*), fruit flies (*Bactrocera* spp.), phytophagous mites (Tetranychidae), whiteflies (*Bemisia tabaci*), leaf miners (*Liriomyza* spp.), and root-knot nematodes (*Meloidogyne* spp.).



Cutworms (*Agrotis* spp.)	Fruit borers (*Helicoverpa armigera*)	Fruit flies (*Bactrocera* spp.)	Phytophagous mites (Tetranychidae)	Whiteflies (*Bemisia tabaci*)	Leaf miners (*Liriomyza* spp.)

- **Phytopathogenic Diseases:** Damping-off (*Pythium* and *Rhizoctonia* spp.), fruit rot (*Colletotrichum* spp.), late blight (*Phytophthora infestans*), leaf spot (*Septoria lycopersici*), and powdery mildew (*Leveillula taurica*).

On-Farm Solid-State Fermentation of Fungal Biopesticides

To facilitate low-cost, decentralized biological control, solid-state fermentation protocols can be implemented at the farm scale to multiply beneficial entomopathogenic and antagonist fungi, including *Trichoderma* spp., *Metarhizium anisopliae*, *Beauveria bassiana*, and *Lecanicillium lecanii* (formerly *Verticillium lecanii*).



Damping-Off (*Pythium* Spp.)	Fruit Rot (*Colletotrichum* Spp.)	Late Blight (*Phytophthora infestans*)	Leaf Spot (*Septoria lycopersici*)	Powdery Mildew (*Leveillula taurica*)

1. Substrate Preparation and Hydration

Sorghum (*Sorghum bicolor*) grains serve as the primary carbon and nutrient substrate, though alternative cereal matrices such as wheat, pearl millet, barley, maize, or potato tubers are viable substitutes. Grains are immersed in water for 24 hours to achieve complete imbibition and hydration. Floating organic debris and non-viable seeds must be skimmed off. If thermal

restriction or cold ambient temperatures impede adequate swelling within 24 hours, the grains must be decocted (boiled) for 20–30 minutes until they achieve structural softening. Approximately 250 g of the hydrated substrate is transferred into high-density polyethylene (HDPE) bags. The terminal ends are secured using high-tensile rubber bands without folding the plastic margins, preventing explosive structural failure under thermal pressure.

2. Autoclaving and Hydrothermal Sterilization

The prepared substrate bags are placed into a vertical pressure cooker or autoclave unit equipped with a baseline water volume of 0.5–1.0 L. To prevent direct thermal melting, bags must be elevated on an internal wire rack or wooden chassis rather than resting directly on the vessel floor. Sterilization is executed over a low, regulated flame for 15 minutes once peak pressure is reached. Following thermal treatment, the unit is allowed to depressurize naturally. The bags are removed only after cooling to ambient temperature; maintaining hermetic closure during this cooling phase is mandatory to avoid exposure to airborne contaminants and opportunistic saprophytic microflora.

3. Aseptic Inoculation and Incubation Dynamics

Inoculation is performed adjacent to an open candle flame to maintain localized air sterility. A sterile 5 mL syringe needle is heated to incandescence over the flame. To equilibrate pressure and ease extraction, sterile air from the thermal zone is drawn into the syringe and injected into the pure *Trichoderma* liquid culture vial, after which the liquid inoculum is drawn. Each substrate bag is inoculated with 4–5 drops of the liquid culture. Upon needle withdrawal, a secondary rubber band is immediately wrapped beneath the puncture site to reseal the hermetic barrier. The inoculated substrate is thoroughly agitated to distribute spores uniformly and incubated in a dark, climate-buffered room. Shaking or mechanical disturbance must be avoided during incubation.

4. Biomass Expansion and Field Application

The completion of the colonization cycle is signaled when the substrate turns uniform dark green, indicating dense sporulation. For foliar applications, the colonized grain mass from one bag is suspended in 10–20 L of water, filtered, and supplemented with 100 g of dissolved jaggery. The jaggery acts as a carbon feeding source for the germinating spores and functions as a natural surfactant/sticker. Spraying must be scheduled exclusively during late evening to protect the fungal propagules from ultraviolet (UV) degradation.

For broader soil inoculation, the colonized grain mass is incorporated into 10–20 kg of humified farmyard manure (FYM). This blend is shaded, covered with damp jute sacks, and misted regularly to preserve moisture. Within 1–2 weeks, a distinct white, hyphal network (mycelium) will envelop the matrix. This stock culture can be mixed with larger volumes of FYM for field-scale application.

5. Rhizosphere Soil Treatment

For standing crops, the enriched biopesticide-FYM matrix is broadcast uniformly across the field immediately prior to a scheduled irrigation event. Subsequent watering facilitates the downward migration of fungal spores into the root zone. This rhizosphere treatment actively suppresses soil-borne wilt complexes and enhances phosphorus bioavailability via microbial organic acid secretion.

Ontogenetic Harvesting Stages and Yield Dynamics

The optimal physiological stage for harvesting is dictated by target market logistics and transit distances. For long-distance supply chains, fruits are harvested at the **breaker/mature-green stage**, morphologically defined as the point when approximately 25% of the blossom end exhibits a pink or light-yellow coloration. Adhering to the prescribed organic management protocol yields substantial variations based on genetic architecture:

- **Open-Pollinated/Improved Cultivars:** Achieve a cumulative yield of approximately 30–45 t ha^{-1} (300–450 q ha^{-1}).
- **F1 Hybrid Cultivars:** Demonstrate superior heterosis, yielding 45–65 t ha^{-1} (450–650 q ha^{-1}), with elite hybrids occasionally exceeding these parameters under optimized environmental conditions.

Post-Harvest Physiology and Cold Chain Storage

Tomato fruit longevity and respiratory dynamics are highly sensitive to ambient post-harvest environments. Ripe tomatoes maintain shelf-life stability for approximately 10 days under standard ambient room temperature regimes during the breaker-to-turning phase. For extended storage up to 30 days, fruits must be held within a regulated cold-chain environment at a temperature of 10–15°C paired with a relative humidity (RH) of 80–85% to suppress ethylene production and senescence.

Volume: 06 Issue No: 09

OSMOTIC STRESS: CAUSES AND THEIR REMEDIES

Article ID: AG-VO6-I09-116

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture,

Jobner, Rajasthan-303329, India

Introduction

Osmotic stress is a condition in which plants are unable to absorb sufficient water from the soil because the water potential of the soil solution becomes too low. It occurs mainly when the soil contains too much salt or when there is insufficient water. In simple words, osmotic stress means a shortage of physiologically available water to plant cells, even when some water may be present in the soil. It is an important component of drought stress and salinity stress.

Types of Osmotic Stress: Osmotic stress in plants can broadly be divided into:

A. Drought-induced osmotic stress

It occurs when there is inadequate water in the soil due to:

i.Low rainfall ii. Prolonged dry periods iii. High temperature

iv. High evaporation v. Inadequate irrigation

B. Salinity-induced osmotic stress: It occurs when excessive soluble salts accumulate in the soil solution. Common salts include:

i. Sodium chloride (NaCl) ii. Sodium sulphate

iii. Calcium salts iv. Magnesium salts

High salt concentration decreases soil water potential and makes water uptake difficult.

C. Combined drought and salinity stress

In arid and semi-arid regions, plants may experience **both water deficit and soil salinity simultaneously**, producing severe osmotic stress.

Causes of Osmotic Stress

Major causes include:

i. Water scarcity or drought ii. Low and irregular rainfall

iii. High soil salinity iv. Excessive irrigation without proper drainage

v. Accumulation of salts in the root zone vi. High temperature and evaporation

vii. Poor soil structure viii. Waterlogging followed by salt accumulation

ix. Use of saline irrigation water x. High atmospheric evaporative demand

xi. Climate change and prolonged dry periods

Effects of Osmotic Stress on Plants

Osmotic stress affects plants at physiological, biochemical and morphological levels.

A. Reduced water uptake

Low soil water potential reduces the ability of roots to absorb water. Consequently, plants experience **cellular dehydration**.

B. Reduction in cell turgor: Water loss causes a reduction in cell turgidity. This results in:

i. Wilting ii. Leaf rolling iii. Reduced leaf expansion iv. Reduced growth

C. Reduction in photosynthesis: Osmotic stress causes stomatal closure, which reduces CO_2 entry into leaves. It therefore decreases:

i. Photosynthetic rate ii. Chlorophyll activity iii. Carbon assimilation

D. Reduction in plant growth

Cell division and cell expansion are inhibited, resulting in:

i. Shorter plants ii. Smaller leaves iii. Reduced root and shoot growth iv. Reduced biomass

E. Stomatal closure: Plants close their stomata to reduce water loss through transpiration. However, prolonged stomatal closure also reduces photosynthesis.

F. Oxidative stress: Osmotic stress can increase the production of **reactive oxygen species (ROS)** such as:

i. Superoxide radicals ii. Hydrogen peroxide iii. Hydroxyl radicals

Excess ROS can damage membranes, proteins, enzymes and nucleic acids.

G. Membrane damage: Severe osmotic stress can increase membrane permeability and cause leakage of cellular electrolytes.

H. Nutrient imbalance: Particularly under salinity, osmotic stress can interfere with the uptake and transport of essential nutrients such as:

i. Potassium ii. Calcium iii. Magnesium iv. Nitrogen

I. Changes in flowering and fruiting: Severe stress may cause:

i. Poor flowering ii. Flower abortion iii. Reduced fruit set

iv. Smaller fruits v. Premature fruit drop vi. Reduced yield

J. Reduction in yield and quality: Ultimately, prolonged osmotic stress can substantially reduce **crop productivity, fruit quality and economic returns**.

Plant Mechanisms for Tolerance to Osmotic Stress

Plants have several natural mechanisms to tolerate osmotic stress.

1. Osmotic adjustment: Plants accumulate compatible solutes such as:

i. Proline ii. Soluble sugars

iii. Glycine betaine iv. Amino acids

These substances help maintain cell water status without seriously interfering with cellular metabolism.

2. Antioxidant defence: Plants increase antioxidant enzymes such as:

i. Superoxide dismutase (SOD) ii. Catalase (CAT)

iii. Ascorbate peroxidase (APX) iv. Glutathione reductase (GR)

These help detoxify excessive ROS.

3. Root system modification: Plants may develop deeper or more extensive root systems to access available soil moisture.

4. Stomatal regulation: Stomatal closure helps reduce excessive water loss through transpiration.

5. Ion regulation: Under salinity, tolerant plants restrict excessive Na^+ accumulation in sensitive tissues and maintain a better **K^+/Na^+ balance**.

6. Practices to Overcome or Reduce Harmful Effects of Osmotic Stress

A. Proper irrigation management

I. Apply irrigation according to crop requirement.
II. Use **drip or micro-irrigation** where appropriate.
III. Avoid excessive irrigation.
IV. Irrigate during critical growth stages.
V. Maintain adequate soil moisture.

B. Improve soil drainage: Good drainage prevents the accumulation of salts in the root zone. Practices include:

i. Drainage channels ii. Raised beds where appropriate

iii. Subsurface drainage in problem soils iv. Avoiding prolonged waterlogging

C. Use mulching: Organic or plastic mulch can reduce:

i. Soil evaporation ii. Soil temperature fluctuations iii. Moisture loss

Organic mulches also improve soil organic matter over time.

D. Selection of tolerant varieties: Use **drought-tolerant and/or salt-tolerant cultivars and rootstocks** suitable for the local environment.

E. Soil amendments: For saline/sodic soils, appropriate amendments may include:

I. **Gypsum** for sodic soils where recommended
II. Organic manure
III. Compost
IV. Biochar in suitable situations

The amendment should be selected according to soil-test results.

F. Seed priming: Seed priming can improve:

i. Germination ii. Seedling establishment

iii. Early vigour iv. Tolerance to water and salinity stress

Different approaches include hydropriming, osmopriming and chemical/biological priming.

G. Foliar application of protective substances: Depending on crop and research recommendations, substances such as:

i. Salicylic acid ii. Brassinosteroids

iii. Certain osmoprotectants iv. Seaweed-based biostimulants

may improve stress tolerance. **Concentration and timing should be crop-specific**, because excessive application can itself cause injury.

H. Use of beneficial microorganisms: Mycorrhizal fungi and selected plant-growth-promoting microorganisms may improve:

i. Root development ii. Nutrient uptake

iii. Water-use efficiency iv. Tolerance to drought and salinity

I. Maintain balanced nutrition: Adequate supply of nutrients, particularly **potassium and calcium**, can support water relations and membrane stability. Fertilization should be based on soil and crop requirements.

J. Weed management: Weeds compete with crops for limited soil water. Timely weed control can therefore reduce water stress.

K. Conservation agriculture: Useful practices include:

i.Minimum soil disturbance ii. Residue retention

iii. Mulching iv. Crop rotation

v. Cover crops

These practices can improve soil structure and water conservation.

7. Importance of Managing Osmotic Stress: Management of osmotic stress is particularly important in **arid and semi-arid agriculture**, where water scarcity, high temperature, and soil salinity frequently occur.

Effective management helps to:

i. Maintain plant water status ii. Improve photosynthesis

iii. Maintain growth iv. Improve flowering and fruit setting

v. Reduce oxidative damage vi. Improve nutrient uptake

vii. Increase crop yield viii. Improve fruit quality

ix. Increase water-use efficiency x. Improve agricultural sustainability

Conclusion

Osmotic stress is a major environmental constraint that limits plant growth and productivity, particularly under drought and salinity conditions. It reduces water uptake, cell turgor, photosynthesis and nutrient balance and may cause oxidative damage, poor reproductive development and yield losses. Plants possess natural mechanisms such as osmotic adjustment, antioxidant defence, stomatal regulation and ion homeostasis to tolerate stress. However, these mechanisms can be strengthened through appropriate agricultural practices such as efficient irrigation, improved drainage, mulching, tolerant varieties, balanced nutrition, seed priming, suitable biostimulants and beneficial microorganisms.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

PLANT AMLA - A WONDER FRUIT TREE OF WASTELANDS

Article ID: AG-V06-I09-117

K.Kalaichelvi[1] and P. Murali Sankar[2]

[1] Assistant Professor (Agronomy), KVK , Vridhachalam - 606 001

[2] Assistant Professor (Plant Pathology), Assistant Professor (Plant Pathology),

RVS college of Horticulture, Sempatti – 624707

*Corresponding Author : K.Kalaichelvi

Introduction

Amla is a hardy , rainfed and drought tolerant fruit tree. It is tolerant to salinity and alkalinity also. Hence this is widely grown in less fertile rainfeds of Tamil Nadu. 1 acre of land is allocated to Amla in many of the Farms because of its flexibility to versatile environments and demand in market. It can withstand very harsh temperatures of more than 45^0C. In waste lands and Prosopis infested areas this tree and also citrus ‘Lemon’ or ‘Acid lime’ are recommended. disease and pest infestation is lesser in Amla.



Uses

Phyllanthus emblica Linn. or *Emblica officinalis* Gaertn. commonly known as Indian gooseberry or Amla. *Emblica officinalis* (Amla) are widely used in the Indian system of medicine (Ayurveda, Unani and Siddha). According to believe in ancient Indian mythology, it is the first tree to be created in the universe. It belongs to the family of Euphorbiaceae. It is the richest natural source of Vitamin C. It primarily contains tannins, alkaloids, phenolic compounds, amino acids and carbohydrates. Its fruit juice contains the highest amount of vitamin C, Ellagic acid, Chebulinic acid, Quercetin, Chebulagic acid, Emblicanin-A, Emblicanin-B, Gallic acid and ascorbic acid etc. all parts of amla are useful in the treatment of various diseases but the most important part is fruit.

Amla fruit is widely used in the Indian system of medicine as diuretic, laxative, liver tonic, refrigerant, stomachic, restorative, anti-pyretic, hair tonic, ulcer preventive and also useful for common cold, fever; as alone or in combination with other plants. The fruit is used as a major constituent in several Ayurvedic preparations such as Chyavanprash and Rasayana which promotes health and longevity. Regular use of amla improves immunity, fight against cancers, chronic diseases like hypertension, high Cholesterol, Diabetes, influenza, Chronic cough and cold, chronic infections, Chronic fatigue and Chronic inflammatory conditions. According to Ayurveda amla is one of the best herbs for Diabetes, bleeding disorders, strength and stamina promoter. E. officinalis is also suitable for used as a anti-aging, sunscreen and general purpose for skin care products.

AMLA: A natural wonder

It is one of the precious gifts of nature to mankind. Fruit known in Sanskrit as Amalaka, Hindi- Amla, Tamil- Nellikai, Bengali- Amalaki, Nepalese- Amala, TeluguUsirikai,. Amla is a high rich source of vitamin C, among 1 gm of vitamin C per 100 ml fresh juice, and requisite for the synthesis of collagen, which is liable for keeping the cells of the body together. It increases the red blood cell count and helps to promote good health. Numerous experimental evidences have shown that amla fruit possess antiinflammatory, antioxidant, Hepatoprotective and hypocholesterolemic activities. Vitamin C present in amla is one of the main factors that can help to retrieve or refill the energy lost by body. So, the replenishment of new energy causing by amla is considered as a natural refreshner.

Chemical Constituents of Amla

Amino acids	Glutamic acid, Proline, Aspartic acid, Alanine, Cystine, Lysine
Hydrolysable Tannins	Emblicanin A and B, Punigluconin, Pedunculagin, Chebulinic acid (Ellagitannin), Chebulagic acid (Benzopyran tannin), Corilagin (Ellagitannin), Geraniin (Dehydroellagitannin), Ellagotannin
Alkaloids	Phyllantine, Phyllembein, Phyllantidine Fatty acids linoleic acid, linolenic acid, stearic acid, oleic acid, palmitic acid and myristic acid
Phenolic compounds	Gallic acid, Methyl gallate, Ellagic acid, Trigallayl glucose
Carbohydrates	Pectin
Vitamins	Ascorbic acid (vitamin C)
Flavonoids	Quercetin, Kaempferol
Organic acids	Citric acid

It is widely quoted that; one fresh gooseberry is equal to consuming 16 bananas or 3 oranges or 2 apple. A variety of phytochemical such as flavonoids, tannins, terpenoids and alkaloids are reported to indicate several pharmacological properties such as antioxidant, anticancer, antitumor, antigenotoxic, and ant carcinogenic effects.

Production technology of Amla

Varieties

Banarasi, NA7, Krishna, Kanchan, Chakalya and BSR1

Mode of propagation

Seedlings, graftings and buddings

Planting season : July - August

Spacing

6x6 m

Fertilizers

Fertilizers to be applied per tree during rainy season

FYM	10 kg
N	200g
P	500g
K	200g

Yield : 100kg/tree annually

Fruiting period: Mid September to end of December

Major Markets in Tamil Nadu

Koyembedu market, Chennai, Ottanchatiram

Preferred variety: BSR1 and NA7

Volume: 06 Issue No: 09

POOR MAN'S COW (GOAT) REARING STATUS IN RAJASTHAN

Article ID: AG-VO6-I09-118

[1]D.K. Bagri and [2]D.L. Bagdi*

[1]Subject Matter Specialist, Krishi Vigyan Kendra, Nagaur-II, Maulasar,

Agriculture University Jodhpur -341506, India

[2]Department of Plant Pathology, S.K.N. College of Agriculture, Jobner (Rajasthan)-303329, India

*Corresponding Author: D.L. Bagdi

Introduction

Goat rearing is vital for farmers because it provides low investment costs, steady supplemental income, and high adaptability to harsh environments. Often called the "poor man's cow," it supports rural livelihoods with minimal resources.

Financial and Economic Benefits

Low Capital: Requires small starting capital and simple housing compared to cattle.

Quick Returns: High fertility rates and frequent twin births allow herds to grow fast.

Financial Insurance: Acts as a living savings account that farmers can sell quickly during emergencies.

Management and Feeding Advantages

Easy Care: Can be easily managed by women and children, supporting family labor.

Tough Diets: Efficiently survive on local shrubs, tree leaves, and rough terrain where crops fail.

Small Space: Require very little room and adapt well to different climates.

Farm and Family Support

Multiple Products: Provide a steady supply of meat, milk, and skin, plus rich organic manure for crops.

Easy Milk: Goat milk is nutritious and easier to digest than cow milk.

Nutritional values of goat milk

Goat milk is a rich source of protein, calcium, and potassium. One cup (244g) of whole goat milk contains **168 calories**, **9 grams of protein**, and **10 grams of fat**.

Key Nutrients (Per 1 Cup)

1.Calories: 168 **2. Protein:** 9 g **3. Fat:** 10 g

4.Carbohydrates: 11 g **5. Calcium:** 327 mg (33% Daily Value)

6. Potassium: 498 mg (14% Daily Value)

Health Properties

Easy Digestion: Smaller fat globules and different protein structures help your body break it down faster than cow milk.

High Minerals: Provides more calcium, phosphorus, and magnesium than standard dairy milk.

Lactose Note: It still contains lactose (milk sugar), so it is not completely lactose-free

Goat milk benefits and side effects

Goat milk offers key nutritional advantages including easier digestion, high calcium, and complete protein, but it can cause side effects like allergic reactions, digestive issues from lactose, and severe food poisoning if consumed unpasteurized.

Goat milk benefits

Faster Digestion: Contains smaller fat globules and softer curds that break down rapidly in the stomach.

Rich in Minerals: Provides high amounts of calcium, phosphorus, potassium, and magnesium for bone and heart health.

Complete Protein: Supplies essential amino acids required for muscle repair and metabolic function.

Potential side effects

Lactose Discomfort: Contains natural lactose, meaning it can still trigger bloating or gas in people with lactose intolerance.

Allergy Risks: Can cause cross-reactivity or allergic reactions in people sensitive to dairy proteins.

Raw Milk Dangers: Drinking unpasteurized goat milk risks severe infections like brucellosis, E. coli, or salmonella.

Unsafe for Infants: Lacks the proper balance of nutrients needed for babies under one-year-old

Goat milk benefit for liver

Goat milk supports liver health by reducing inflammation, preventing fat accumulation (hepatic steatosis), and offering hepatoprotective effects. Its high concentration of Medium-Chain Triglycerides (MCTs) allows for rapid energy absorption that bypasses complex liver metabolism, while its antioxidant profile helps mitigate drug-induced liver damage.

Goat milk provides several key benefits for the liver

Eases Liver Workload: Goat milk is naturally rich in Medium-Chain Triglycerides (MCTs). Unlike long-chain fats, MCTs are quickly absorbed and metabolized, providing an efficient energy source that puts less strain on the liver.

Reduces Liver Inflammation and Fatty Liver: Research indicates that goat milk's unique fatty acid profile can prevent hepatic steatosis (fatty liver) and reduce liver inflammation, especially when managing high-fat diets.

Protects Against Damage: Studies suggest that goat milk can exert hepatoprotective (liver-protecting) effects. It acts as an antioxidant to shield the liver from damage caused by toxins or medications.

Improves Iron Metabolism: Fermented goat milk has been shown to favorably regulate key liver genes and proteins involved in iron metabolism, optimizing iron storage and preventing toxic overload

Major Native Breeds of goats adopted by farmers in Rajasthan

The most famous goat breeds native to Rajasthan are Sirohi, Marwari, and Sojat, celebrated for their high adaptability, meat, and milk production.

Top goat breeds in Rajasthan

1. Sirohi

Origin: Sirohi district, spread across Ajmer, Bhilwara, and Udaipur.

Traits: Brown coat with light or dark patches, flat leaf-like drooping ears, medium size, and hardy nature.

Use: Dual-purpose for milk and meat.

2.Marwari

Origin: Marwar region (Jodhpur, Barmer, Jaisalmer, Pali).

Traits: Distinctly black coat, long hair, pendulous ears, and high resistance to arid desert conditions.

Use: Valued for meat, milk, and coarse wool.

3.Sojat

Origin: Pali and Jodhpur districts, centered around Sojat.

Traits: Generally white coat with occasional black or brown spots, long drooping ears, and a large body frame.

Use: Primarily raised for high-quality meat.

4.Jakhrana

Origin: Behror tehsil of Alwar district.

Traits: Deep black coat with white spots on the ears and muzzle, compact large body.

Use: Excellent dairy breed with high daily milk yield.

5.Karauli (Kota)

Origin: Karauli, Kota, and Sawai Madhopur districts.

Traits: Black or brown coat with white markings, robust build, and fast weight gain.

Use: Highly profitable dual-purpose breed for milk and tender meat.

Common feed, fodder and concentrates for goat in rajasthan

Goat feeding in Rajasthan relies on community grazing, native shrubs, and crop residues, supplemented by local green fodders and high-energy concentrate mixes.

Common Forage and Grazing

Native Shrubs & Trees: Browsing on *babul* (*Acacia nilotica*), *neem* (*Azadirachta indica*), and local thorny bushes.

Community Pastures: Free-range grazing on native arid grasses and weeds for over 5 hours daily.

Green and Dry Fodder

Green Fodder: Cultivated crops like sorghum (*jowar*), pearl millet (*bajra*), cluster bean (*guar*), and lucerne (*alfa-alfa*) when available.

Dry Fodder: Crop residues including wheat straw (*wheat bhusa*), pearl millet stover (*bajra karab*), and pulse crop wastes (chickpea/moong straw).

Concentrates and Supplements

Energy Bases: Crushed maize or barley grains.

Protein Cakes: Mustard oil cake (mustard DOC) as the regional standard, alongside groundnut cake.

By-products & Minerals: Wheat bran, de-oiled rice bran (DORB), common salt, and commercial mineral mixtures fed at 200–400 grams daily for milking or growing goats

Breeding practices of goat adopted by farmers

Goat farmers mainly adopt natural mating, select breeding bucks based on body size and physical appearance, and allow uncontrolled or flock breeding rather than using artificial insemination.

Selection and Age for Breeding

Age at first mating: Does (female goats) are usually bred when they are 12 to 18 months old.

Buck selection: Farmers choose male bucks based on large body weight, strong physical form, and local breed traits (such as Marwari or Jamunapari).

Ratio: A common practice is keeping one active breeding buck for every 25 to 30 does.

Mating and Heat Detection

Natural service: Almost all smallholder farmers rely entirely on natural mating instead of artificial insemination.

Heat signs: Farmers spot females in heat by watching for tail wagging, frequent urination, bleating, and attempts to mount other goats.

Flock mating: Many keep the male inside the general herd for a set period or practice year-round open mating without strict pedigree records.

Acknowledgements: We would like to thank the Krishi Vigyan Kendra, Nagaur-II, Maulasar, Agriculture University Jodhpur for the financial support of publication of this article.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

ASSESSING THE ECOLOGICAL CONSEQUENCES OF ANTHROPOGENIC ACTIVITIES ON AQUATIC BIODIVERSITY AND ECOSYSTEM HEALTH

Article ID: AG-VO6-I09-119

Shafiya Mushtaq [1*], Ishrat Mohamad [1], Tasaduq Hussain Shah [1] and Saima Jan

[1]Faculty of Fisheries, Sher-e Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K), Rangil-190006, Ganderbal

*Corresponding Author : Shafiya Mushtaq

Abstract

Aquatic ecosystems are increasingly threatened by human-induced interventions that disrupt their structural and functional integrity. This article explores the multifaceted impacts of anthropogenic activities, including damming, river interlinking, seawall construction, micro-hydropower development, and offshore oil extraction, on aquatic biodiversity. While such interventions are often justified by socio-economic development goals, they contribute to habitat fragmentation, altered hydrological regimes, and biodiversity loss. These activities not only result in species composition changes and population size decline but also impede essential ecological processes like nutrient cycling, migration, and spawning. The end result of these impacts is particularly visible in ecologically sensitive areas like estuaries, coastal zones, and riverine freshwater basins. Based on case studies and empirical observations, this research brings to the fore the imperative necessity of environmental governance, restoration measures, and eco-centric planning to reduce degradation. The paper emphasizes the need for the incorporation of sustainable infrastructure planning, environmental impact assessments, and long-term conservation policies to preserve aquatic ecosystems for future generations.

Keywords: Aquatic biodiversity, Anthropogenic impact, Hydropower, Oil exploration, Habitat fragmentation, Conservation,

Introduction

Human activities, generically referred to as anthropogenic interventions, have overwhelmingly affected aquatic biodiversity worldwide. The activities are pollution, habitat

destruction, construction of dams, overfishing, river interlinking, and introduction of alien species. Such interventions are performed in the interest of development, flood control, energy generation, and coastal defense, but their ecological effects are immense. They alter hydrological regimes, divide habitats into pieces, and provide migration barriers, devastating aquatic life.

These interventions, as reported by Dudgeon *et al.* (2006), are significant causes of freshwater and marine biodiversity loss. Aquatic organisms, especially those dependent on specialized flow regimes or habitats, are susceptible to changes in water quality, flow regime, and connectivity. Such resultant imbalances can cause extinction or endangerment of indigenous species. Damming of rivers is one of the most significant anthropogenic changes to freshwater ecosystems. Though dams provide various socio-economic benefits, such as irrigation, hydroelectricity, and flood control, they break up habitats and change river flows (Nilsson et al., 2005). Fish like salmon (*Oncorhynchus* spp.), eel (Anguilla spp.), and mahseer (Tor spp.) are greatly impacted because they rely on unobstructed migration corridors for spawning. The disturbance of natural flow regimes impacts the timing and availability of spawning habitats, usually with a strong reduction in reproductive achievement. Apart from damming migratory routes, dams can decrease upstream-downstream habitat connectivity, altering sediment transport and nutrient cycling. This change affects aquatic invertebrates, larval fish, and floodplain vegetation that are dependent on seasonal flooding. Reservoirs behind dams flood extensive areas of riverine and terrestrial ecosystems, causing loss of habitats and local community displacement.

Ecological Impacts

- Disrupted Fish Migration: Catadromous and anadromous species are subject to reproductive failure as migratory routes are blocked.
- Habitat Loss: Rivers are turned into still reservoirs, changing oxygen levels, temperature, and sediment transport.
- Species Replacement: Invasive species such as African catfish replace native species that decrease in number.
- Water Quality Alteration: Sediment trapping reduces nutrients downstream. Cold water releases from the bottom of dams negatively impact temperature-sensitive organisms.

Instances such as China's Three Gorges Dam have led to habitat destruction for more than 25 native fish species (Fu *et al.*, 2003). In India, dams including Bhakra Nangal, Tehri, and Sardar

Sarovar have also affected biodiversity in large rivers such as the Ganges, Yamuna, and Narmada.

River Interlinking

River connecting schemes reallocate water from excess to deficit areas, mostly for agriculture and drinking purposes. But they undermine the environmental health of whole basins. They link otherwise separated ecosystems, making it easy for invasive species and waterborne diseases to spread (Zarfl *et al.,* 2019). India's Ken-Betwa scheme is a case in point. It threatens to flood key habitats in the Panna Tiger Reserve and change hydrological regimes in the Bundelkhand region. Those types of projects tend to contribute to homogenized water chemistry, derailed seasonal flows, and loss of endemic fauna. In addition to species-level effects, river interlinking changes sediment transport patterns and leads to upstream and downstream erosion or siltation. Altered flow regimes can uproot aquatic vegetation, impair fish breeding cycles, and lower floodplain fertility. The resulting environmental simplification makes ecosystems more susceptible to climate change and anthropogenic stressors.

Further, socio-economic impacts in terms of displacement of people, alteration of livelihood for riparian dwellers, and long-term water redistribution unsustainability need to be taken into consideration. It has been observed through research that inter-basin transfers usually do not produce consistent ecological or economic returns in the long term and can worsen the water stress in donor areas during the dry cycles. Hence, such a large-scale hydrological construction needs strong ecological evaluations, participatory planning, and long-term monitoring systems.

Construction of Seawalls

Seawalls are constructed with the aim of safeguarding coastal structures against erosion and sea-level rise but have significant ecological implications. They destroy beaches, tidal flats, and salt marshes, which are important spawning and feeding grounds for marine species (Bulleri & Chapman, 2010). Seawall development in India's Kerala has also been associated with the reduction of Olive Ridley turtle (Lepidochelys olivacea) nesting, as natural mounds of sandy beaches were lost (Kumar & Jayasankar, 2013). The effect of "coastal squeeze"—trapping habitats against hard infrastructure with rising sea levels—aids in this loss. Seawalls also disrupt natural sediment transport patterns, tending to intensify adjacent beach erosion areas that do not enjoy these protections. This triggers a cycle of coastal deterioration, leading to increased hard

infrastructure construction and amplifying environmental harm. Seawalls also reflect rather than absorb wave energy, further intensifying seabed scouring and negatively impacting benthic communities. Sea organisms that depend on dynamic coastal ecosystems like horseshoe crabs, some shellfish, and intertidal fish see their habitats fragmented and their populations depleted. Disruption of natural tidal flow may also decrease nutrient cycling and primary productivity in nearshore habitats.

In most places, there are other measures such as living shorelines, mangrove forest establishment, and dune protection that are being tried as more sustainable and ecologically friendly strategies of coastal protection. Not only do these nature-based techniques protect infrastructure, but they also conserve essential ecological processes and improve the resilience of biodiversity.

Micro-Hydropower Projects

Generally regarded as green, micro-hydel projects (<10 MW) may have out-of-proportion environmental impacts when developed at scale. The systems fragment stream habitats and interfere with natural flow regimes that are very important for aquatic biodiversity (Anderson et al., 2015). In the Western Ghats of India, microhydel developments have impacted species such as *Puntius denisonii* and *Garra* spp. Even small changes in sediment load or water discharge can cascade impacts on invertebrates and fish. These projects generally avoid environmental impact studies because they are smaller, but collectively, when grouped across a watershed, they are adding to cumulative ecological damage. Changed flow patterns can degrade the transport of organic matter and nutrients and influence the food web from algae to top predators. Micro-hydel development also disrupts temperature control and seasonally recurring flow pulses upon which many species rely for spawning. During the construction phase, involving excavation and road-building, it often results in habitat loss, turbidity, and sedimentation that choke aquatic spawning places. Long-term impacts involve diminishing ecosystem services, including clean water supply and fishery production, especially for riverine-dependent communities. Accordingly, even mini-hydropower required integrated river basin planning and ecological flow studies to reduce impacts.

Offshore Oil Rigs

Offshore drilling and exploration bring physical disruptions and toxic contaminants to marine environments. Heavy metals and hydrocarbons in the drilling muds and cuttings tend to

sink down in the benthic layer, causing intense impact on bottom-dwelling organisms (Cordes *et al.,* 2016). Moreover, seismic noise and activities interfere with cetacean communication and migration (Gordon *et al.,* 2004). The 2010 Deepwater Horizon oil spill that released more than 4 million barrels of oil wreaked havoc on marine life and ecosystems in the Gulf of Mexico (Peterson *et al.,* 2012). The effects of offshore oil rigs reach farther than the drilling platform. Leaks and spills can travel through ocean currents, damaging coral reefs, mangroves, and coastal wetlands. Prolonged exposure to sub-lethal concentrations of pollutants causes damage to marine fauna's reproductive and immune systems. Physical structures like pipelines and platforms can also change existing patterns, seabed integrity, and sediment distribution. They can serve as artificial reefs, luring fish, but also have entrapment hazards and alien species colonization. Mitigation efforts need to incorporate careful monitoring, less-toxic drilling fluids, noise reduction technology, and spill containment emergency response systems. Phasing into renewable sources of offshore energy such as wind and wave power can be an effective way of minimizing long-term reliance on petroleum and its attendant risk to the environment.

Conclusion

Although anthropogenic infrastructure facilitates economic growth, its environmental cost is too often irrecoverable. Aquatic species that are narrowly habitat-restricted are especially vulnerable. Conservation must balance development with protection of the ecosystem through methods such as environmental impact assessments, biodiversity offsets, fish ladders, and green engineering. Sustainable development calls for a systems approach where policy, science, and engineering collaborate to preserve aquatic biodiversity. In addition, raising public awareness and promoting stakeholder participation are important in mitigating environmental effects of human actions. The governance system has to balance the health of the ecosystem with human interests. Promoting nature-based solutions such as green infrastructure, ecological restoration, and integrated watershed management will most likely minimize the adverse effects of human impacts. It is also important to increase global cooperation, information exchange platforms, and enforcement of environmental laws to monitor and prevent cumulative effects on global aquatic ecosystems. Future research should respond to long-term ecological monitoring, development of species-specific conservation plans, and adaptive management strategies responding to ongoing environmental change. In essence, the discovery of balance between human needs and green

wholesomeness is not merely a matter of scientific necessity but one of ethical necessity in the conservation of life on Earth.

References

Adeogun, O. A., & Chukwuka, V. A. (2024). Anthropogenic Impacts as Determinants of Tropical Lake Morphology. *IntechOpen*. https://doi.org/10.5772/intechopen.112274

Anderson, D., Moggridge, H., Warren, P., & Shucksmith, J. (2015). The impacts of 'run-of-river' hydropower on the physical and ecological condition of rivers. *Water and Environment Journal*, 29(2), 268–276.

Bulleri, F., & Chapman, M. G. (2010). The introduction of coastal infrastructure as a driver of change in marine environments. *Journal of Applied Ecology*, 47(1), 26–35.

Cordes, E. E., Jones, D. O. B., Schlacher, T. A., Amon, D. J., Bernardino, A. F., Brooke, S., ... & Levin, L. A. (2016). Environmental impacts of the deep-water oil and gas industry: A review to guide management strategies. Frontiers in Environmental Science, 4, 58. https://doi.org/10.3389/fenvs.2016.00058

Dahanukar, N., Raghavan, R., Ali, A., Abraham, R., & Shaji, C. P. (2011). The status and distribution of freshwater fishes of the Western Ghats. Conservation Assessment and Management Plan (CAMP) Workshop Report. IUCN - India, Zoo Outreach Organisation.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z.-I., Knowler, D. J., Importance, threats, status and conservation challenges. Biological Reviews, 81(2), 163–182. https://doi.org/10.1017/S1464793105006950

Fu, C., Wu, J., Chen, J., Wu, Q., & Lei, G. (2003). Freshwater fish biodiversity in the Yangtze River basin of China: Patterns, threats and conservation. Biodiversity and Conservation, 12(8), 1649–1685. https://doi.org/10.1023/A:1023697714517

Gordon, J. C. D., Gillespie, D., Potter, J. R., Frantzis, A., Simmonds, M. P., Swift, R., & Thompson, D. (2004). A review of the effects of seismic surveys on marine mammals. Marine Technology Society Journal, 37(4), 16–34. https://doi.org/10.4031/002533204787522124.

Kumar, R. S., & Jayasankar, J. (2013). Seawall and coastal erosion along the Kerala coast: Problems and perspectives. *Indian Journal of Geo-Marine Sciences*, 42(5), 579–586.

Nilsson, C., Reidy, C. A., Dynesius, M., & Revenga, C. (2005). Fragmentation and flow regulation of the world's large river systems. Science, 308(5720), 405–408. https://doi.org/10.1126/science.1107887.

Peterson, C. H., Rice, S. D., Short, J. W., Esler, D., Bodkin, J. L., Ballachey, B. E., & Irons, D. B. (2003). Long-term ecosystem response to the Exxon Valdez oil spill. Science, 302(5653), 2082–2086. https://doi.org/10.1126/science.1084282.

Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., ... & Stromberg, J. C. (1997). The natural flow regime. BioScience, 47(11), 769–784. https://doi.org/10.2307/1313099.

Zarfl, C., Berlekamp, J., He, F., Jähnig, S. C., Darwall, W., & Tockner, K. (2019). Future large hydropower dams impact global freshwater megafauna. Scientific

Volume: 06 Issue No: 09

PRECISION AGRICULTURE FOR PRECISION PEST MANAGEMENT

Article ID: AG-VO6-I09-120

[1] Nitish Kumar, L. S. and [2] Chidanand Gowda, M. R.

[1] Department of Agricultural Entomology, College of Agriculture, UAS, GKVK, Bengaluru

[2] Department of Agronomy, College of Agriculture, UAS, V.C. Farm, Mandya, Karnataka, India

*Corresponding Author: Nitish Kumar, L. S

Introduction

Agriculture is entering a new phase in which decisions are increasingly being made not only by observing the whole field, but by understanding what is happening at specific locations within the field. This is the basic idea behind precision agriculture.

Traditional pest management often treats an entire field uniformly: one crop, one spray recommendation and one application rate. But insect pests are rarely distributed evenly. A few patches may contain high pest populations while large portions of the same field remain below the economic threshold. Site-specific pest management uses information on this spatial variation to target management where it is actually needed.

This shift can be summarized simply: **From "spray the field" to "identify the problem, locate the problem and treat the problem."**

What is precision pest management?

Precision pest management is the application of sensing, geospatial technologies, data analysis and targeted control to manage pests according to their actual distribution and severity. It combines agronomy, entomology and digital technologies such as:

- Global Positioning System (GPS)
- Geographic Information System (GIS)
- remote sensing
- drones or unmanned aerial vehicles (UAVs)
- smart insect traps

- field sensors
- artificial intelligence (AI)
- machine learning
- mobile applications
- variable-rate application systems

The fundamental principle is **site-specific management**. Instead of assuming that every part of a field has the same pest pressure, the field is treated as a collection of management zones.

This is particularly relevant because pest populations are naturally patchy. A field of maize (*Zea mays* L.), for example, may contain areas with heavy infestation by fall armyworm, *Spodoptera frugiperda* (J. E. Smith), alongside areas with little or no economically important infestation.

Precision pest management attempts to answer three questions:

- **Where is the pest?**
- **How severe is the infestation?**
- **What action is economically justified?**

This approach connects directly with Integrated Pest Management (IPM). Pest presence alone does not necessarily justify intervention. The pest population, crop stage, economic threshold, natural-enemy activity and expected crop loss should be considered.

Therefore, precision technology does not replace entomological knowledge.

It makes entomological knowledge more spatially precise.

The technology behind precision pest management

1. GPS and GIS: knowing where the pest is

GPS provides the location of pest observations, while GIS converts these observations into pest distribution maps. Areas can be classified as low, moderate or high infestation and linked with crop growth, soil, irrigation and previous pest records. This makes field scouting more spatial and targeted.

2. Remote sensing: seeing crop stress from above

Satellites and UAVs capture crop images using RGB and multispectral sensors. These images help identify variations in crop vigour and stress. However, crop stress does not always mean insect damage; drought, nutrient deficiency and diseases can produce similar patterns. Hence, remote sensing should be supported by ground scouting and entomological diagnosis.

3. Drones: precision from the air

Drones provide high-resolution images for detecting crop variability, pest hotspots and damage. They can also support targeted application. Thus, UAVs can function as both sensing tools for detection and application tools for site-specific management.

4. Artificial intelligence: turning images into information

AI and machine-learning models can analyse large numbers of field images to detect insects, damaged plants or abnormal crop patterns. They can assist in identifying pests such as *Helicoverpa armigera* and *Spodoptera frugiperda*. However, accuracy depends on quality training data, field validation and correct biological interpretation.

5. Smart traps: continuous pest monitoring

Smart traps combine pheromones, sticky surfaces, cameras and sensors to automatically monitor insect activity. They can provide continuous information on adult pest populations and support early warning and timely intervention, reducing dependence on occasional manual observations.

6. Weather data and pest forecasting

Temperature, humidity, rainfall and crop stage influence insect development. Combining weather data + crop stage + pest observations + historical records can help identify periods and locations of increased pest risk, improving the timing of scouting and management.

From detection to management

The precision pest-management process can be simplified as:

Sense → Identify → Map → Analyse → Decide → Target → Evaluate

Field observations are collected using traps, sensors, drones or scouting; the pest is identified and mapped; its population is compared with **economic thresholds** and crop conditions; an appropriate management method is selected and applied only where necessary; and the result is evaluated.

Thus, precision management creates a continuous feedback system rather than a one-time spray decision.

Precision spraying: right place, right dose

Precision spraying aims to apply the right product at the right dose, location and time. Variable-rate application can adjust treatment according to pest distribution instead of treating the entire field uniformly.

Its effectiveness depends on factors such as droplet size, spray volume, wind, canopy density, deposition, drift and operator skill. Therefore, precision spraying requires proper calibration and field validation.

Precision does not always mean pesticides

Precision technology can also strengthen non-chemical IPM approaches:

- **Precision biological control:** focus natural-enemy releases or microbial treatments on pest hotspots.
- **Precision trapping:** position monitoring traps according to pest distribution.
- **Precision scouting:** concentrate field observations in high-risk areas.
- **Precision forecasting:** identify periods of increasing pest risk.
- **Precision crop management:** address agronomic factors contributing to pest outbreaks.

Thus, precision agriculture can **strengthen IPM rather than replace it**.

Table 1. Major technologies used in precision pest management

Technology	What it provides	Potential pest-management application
GPS/GIS	Spatial location and mapping	Mapping pest hotspots and management zones
Satellite remote sensing	Large-area crop information	Monitoring crop stress and landscape patterns
UAV/drone	High-resolution field imagery	Pest/stress detection and targeted intervention
Multispectral/hyperspectral sensors	Spectral information	Detection of crop stress and variability
Smart traps	Automated insect monitoring	Continuous pest surveillance
AI and deep learning	Pattern recognition	Pest/image identification and risk detection
Weather sensors	Local environmental data	Pest forecasting and timing of scouting
Mobile applications	Field data collection and	Farmer-level decision support

	alerts	
Variable-rate technology	Site-specific input application	Targeted pesticide or other input application

The limitations

Precision pest management is promising, but it is not perfect.

1. **Pest detection is difficult:** Some insects are too small to detect directly from aerial imagery.
2. **Symptoms can be misleading:** Nutrient deficiency, drought and disease may resemble insect injury.
3. **AI requires good data:** Poor-quality or regionally biased datasets can reduce model reliability.
4. **Technology can be expensive:** Sensors, drones, software and connectivity require investment.
5. **Field conditions are variable:** Wind, dust, cloud cover, canopy structure and lighting can affect sensing and spraying.
6. **Human expertise remains essential:** An algorithm may detect an unusual pattern, but an entomologist still needs to determine **what caused it and what should be done**.

These limitations mean that precision agriculture should be viewed as a **decision-support system**, not a replacement for field knowledge.

The future: predictive and autonomous pest management

The next stage of precision pest management is moving beyond detection towards **prediction and adaptive decision-making**.

Recent research is exploring combinations of AI, computer vision, UAVs and autonomous systems for site-specific crop protection. A 2026 review describes emerging work on foundation models, adaptive learning and autonomous smart spraying, while noting that fully autonomous systems remain an evolving field.

Conclusion

Precision agriculture is changing the question from: **"**When should we spray the field?" to: "Where is the pest, how much is present, and what is the most appropriate response?". GPS, GIS, remote sensing, drones, smart traps, artificial intelligence and weather-based forecasting are making this approach increasingly possible. But technology alone cannot solve pest problems.

The foundation remains **sound agronomy, accurate insect identification, field scouting, economic thresholds and Integrated Pest Management**.

The real strength of precision pest management lies in combining these principles.

The future may therefore belong not to the farmer who sprays the most accurately, but to the farming system that can **detect problems early, understand their cause, intervene only where necessary and learn from every season.**

From field scouting to drones, sensors and artificial intelligence

Selected References

1. **Matre, Y. B., Lad, A. G., Neharkar, P. S. & Sonkamble, M. M. (2024).** Drone technology in precision agriculture for insect pest management: A short review. *Journal of Entomological Research*, **48**(3), 360–365. https://doi.org/10.5958/0974-4576.2024.00070.6
2. **Huang, Y. et al. (2020).** Drones: Innovative technology for use in precision pest management. *Journal of Economic Entomology*, **113**(1), 1–11.
3. **López-Granados, F. et al. (2020).** Delineation of site-specific management zones for pest control purposes: Exploring precision agriculture and species distribution modeling approaches. *Computers and Electronics in Agriculture*.
4. **Wang, D. et al. (2025).** A survey of unmanned aerial vehicles and deep learning in precision agriculture. *European Journal of Agronomy*, **127477**. https://doi.org/10.1016/j.eja.2024.127477
5. **FAO (2026).** *Smart Farming – The next revolution of agrifood systems*. Food and Agriculture Organization of the United Nations.

Volume: 06 Issue No: 09

MICROPROPAGATION: STAGES AND ITS APPLICATIONS IN AGRICULTURAL, MEDICINAL AND FORESTRY CROPS

Article ID: AG-VO6-I09-121

[1]Swapnajit Behera, [1] Keshav Meena, [1] Deiva Prakash V, [1] Gayathri K B, [1] Durga Prasad T S, [2]Sivaji M

[1]UG Student, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu 606 753

[2]Teaching Assistant Agricultural Biotechnology, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu 606 753

Corresponding Author **:** Swapnajit Behera

Introduction

Micropropagation is a modern plant biotechnology technique used for the rapid multiplication of plants under controlled laboratory conditions through tissue culture methods. It involves the aseptic culture of plant cells, tissues, or organs on a nutrient medium containing essential minerals, vitamins, sugars, and growth regulators. The technique is based on the principle of totipotency, which states that every living plant cell has the potential to regenerate into a complete plant.



Figure 1. Micropropagation

Micropropagation has become an important tool in agriculture, horticulture, medicinal plant production, and forestry because it enables the production of a large number of genetically uniform and disease-free planting materials in a short period. It is especially useful for crops that are difficult to propagate through see conventional vegetative methods.

Definition of Micropropagation

Micropropagation is the in vitro clonal propagation of plants from small explants such as shoot tips, meristems, nodal segments, leaves, or embryos under sterile and controlled environmental conditions.

Principle of Micropropagation

Micropropagation is based on the principle of totipotency, which states that every living plant cell has the genetic potential to regenerate into a complete plant when provided with suitable nutrients, plant growth regulators, and controlled environmental conditions. This remarkable ability enables the rapid production of large numbers of genetically identical plants from a small piece of plant tissue (called an explant).

The process is carried out under aseptic (sterile) conditions to prevent contamination by microorganisms. The explant is cultured on a nutrient medium, commonly Murashige and Skoog (MS) medium, which contains essential mineral salts, vitamins, carbohydrates, and plant growth regulators such as auxins and cytokinins. Cytokinins promote shoot multiplication, while auxins stimulate root formation. By carefully adjusting the concentration of these growth regulators, the explant can be induced to develop into shoots, roots, and eventually a complete plant.

Micropropagation also relies on the controlled environmental conditions of the tissue culture laboratory, including optimum temperature (about 25 ± 2°C), light intensity, photoperiod, and humidity. These conditions ensure rapid growth and successful regeneration of plantlets.

Since the regenerated plants arise from a single parent plant through vegetative propagation, they are genetically identical (clones). This makes micropropagation an effective technique for the mass production of elite, high-yielding, disease-free, and true-to-type planting materials.

Key principles of micropropagation:

Totipotency: Every living plant cell can regenerate into a complete plant.

Aseptic culture: Sterile conditions prevent microbial contamination. **Nutrient medium:** Provides minerals, vitamins, sugar, and other nutrients for growth.

Plant growth regulators: Auxins and cytokinins regulate root and shoot development.

Controlled environment: Temperature, light, and humidity are maintained for optimal growth.

Clonal propagation: Produces genetically uniform and disease-free plants suitable for large-scale cultivation.

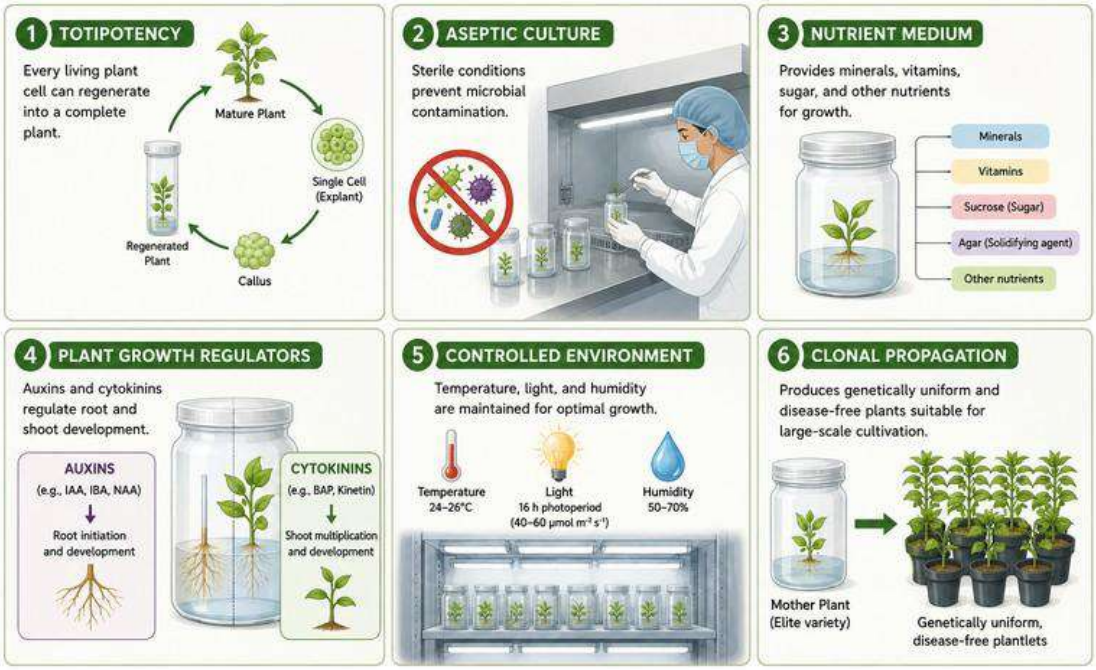


Fig : Key principles of micropropagation

Objectives of Micropropagation

- Rapid Multiplication of Plants

Produce a large number of plants from a small piece of plant tissue in a short period.

- Production of Disease-Free Plants

Generate healthy, virus-free, and pathogen-free planting materials using meristem culture.

- Clonal Propagation

Produce genetically identical (true-to-type) plants that retain the desirable characteristics of the parent plant.

- Conservation of Germplasm

Preserve rare, endangered, and elite plant species for future use and biodiversity conservation.

- Year-Round Plant Production

Enable continuous propagation under controlled laboratory condi

- Propagation of Difficult-to-Root Plants

Multiply plant species that are difficult or slow to propagate through conventional methods.

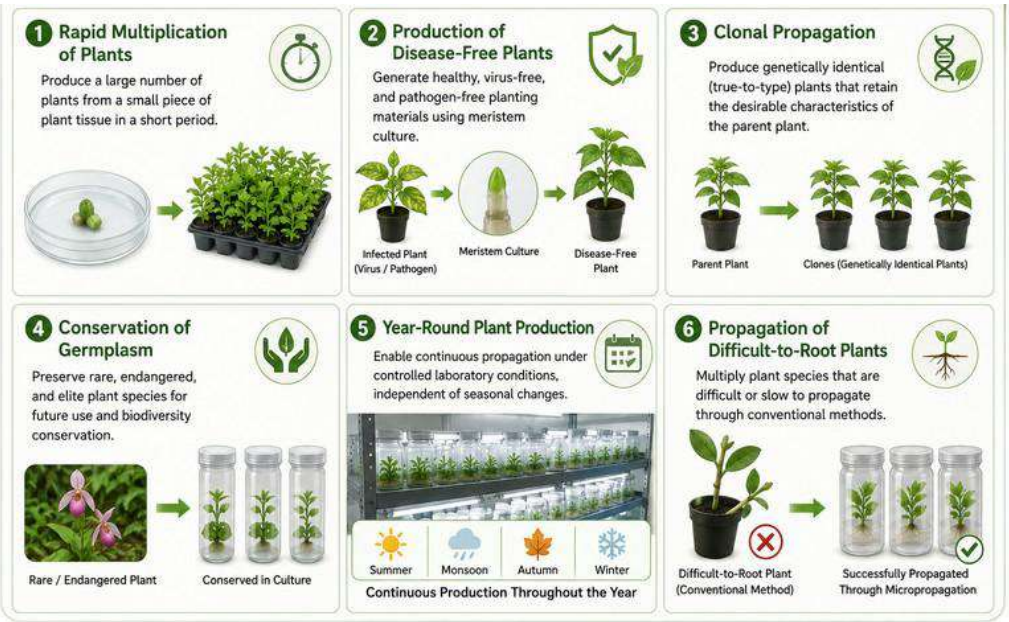


Fig : Objectives of Micropropagation

Stages of Micropropagation

Stage 0: Selection and Preparation of Mother Plant

This is the pre-propagation stage.

Activities

- Selection of healthy, vigorous, and true-to-type mother plants.
- Elimination of pests and diseases.
- Maintenance of stock plants under controlled conditions.

Importance

- Ensures genetic purity.
- Reduces contamination.
- Improves success of culture establishment.

STAGE 0:
SELECTION AND PREPARATION OF MOTHER PLANT

This is the pre-propagation stage.

OBJECTIVE

To select a healthy, high yielding and true-to-type plant and prepare it for explant collection.



CRITERIA FOR SELECTION

- True-to-type and genetically stable
- High yielding and desirable traits
- Disease, pest and virus free
- Vigorous and actively growing
- Adapted to local conditions

STEPS INVOLVED



1. Selection of healthy mother plant
2. Removal of unwanted parts (pruning)
3. Protection from pests and diseases
4. Proper irrigation and nutrient management
5. Collection of suitable explant from mother plant

A well-selected and well-maintained mother plant is the key to successful micropropagation.

STAGE I: ESTABLISHMENT OF EXPLANT

In this stage, healthy plant material is selected and surface sterilized to remove microorganisms. The explant is placed on a sterile nutrient medium.



1. Selection of Healthy Plant

Select a disease-free, vigorous donor plant.

2. Explant Collection

Collect suitable explant (meristem, nodal segment, leaf, etc.).

3. Surface Sterilization

- Wash in running water
- Treat with 70% ethanol (30–60 sec)
- Treat with NaOCl (10–15 min)
- Rinse with sterile distilled water (2–3 times)

4. Inoculation on Nutrient Medium

Aseptically place the sterilized explant on sterile nutrient medium (MS medium).

5. Incubation

Incubate under controlled conditions (temperature 25 ± 2°C, light 16 h/day and humidity).

OBJECTIVES

Obtain contamination-free cultures
Ensure complete removal of all microorganisms to prevent contamination.

Establish healthy tissue growth
Initiate and maintain healthy explant growth for successful multiplication in the next stages.



OUTCOME

Contamination-free, healthy explant established on sterile nutrient medium.

Stage I: Establishment of Aseptic Culture

In this stage, explants are collected and surface sterilized before inoculation on culture medium.

Procedure

- Explant collection (shoot tip, node, meristem, etc.)
- Washing with water and detergent.
- Surface sterilization using ethanol, sodium hypochlorite, or mercuric chloride.
- Inoculation on sterile nutrient medium.

Objective

- To obtain a contamination-free culture that survives and starts initial growth.

Stage II: Multiplication of Shoots

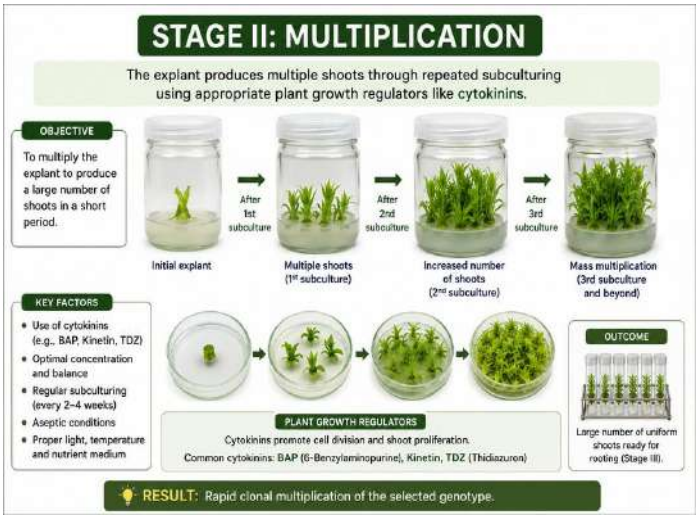
This is the most important stage where rapid proliferation of shoots occurs.

Method

- Transfer established explants to multiplication medium containing cytokinins such as BAP (Benzylaminopurine) or Kinetin.
- Repeated subculturing at regular intervals.

Objective

- To produce a large number of shoots from a single explant



Stage III: Rooting of Shoots

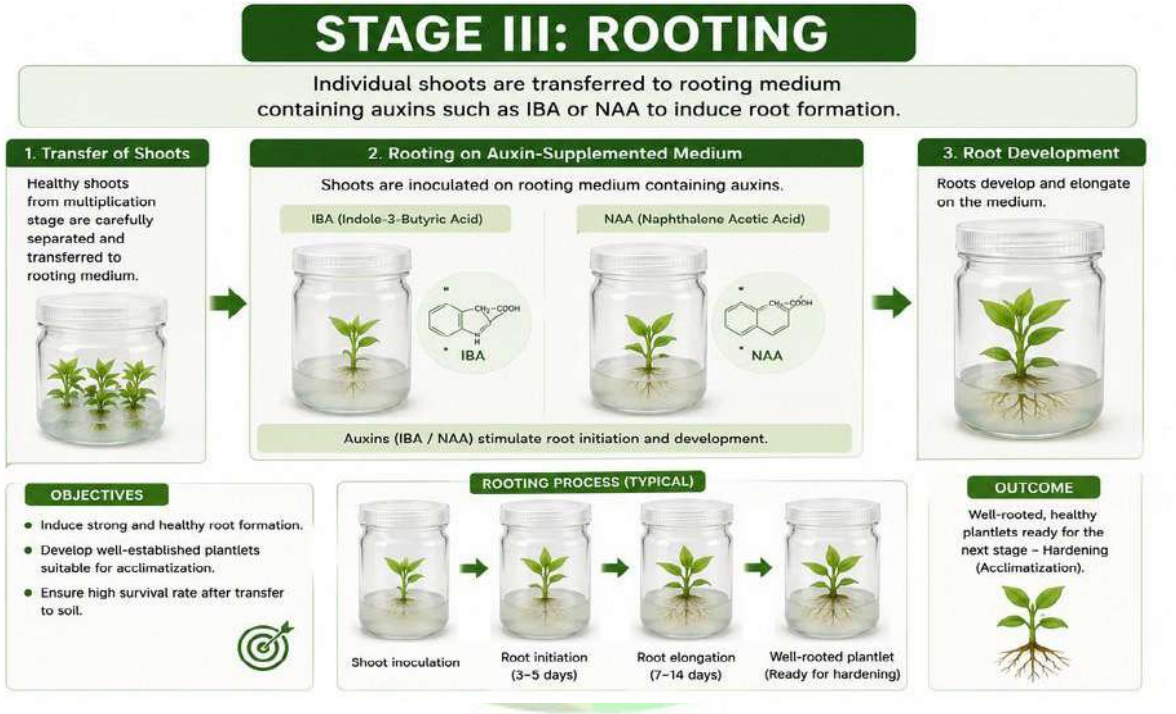
Individual shoots are transferred to a rooting medium.

Growth Regulators

- Auxins such as IBA (Indole-3-butyric acid), IAA (Indole-3-acetic acid), or NAA (Naphthalene acetic acid).

Objective

- Development of a healthy root system.



Stage IV: Hardening and Acclimatization

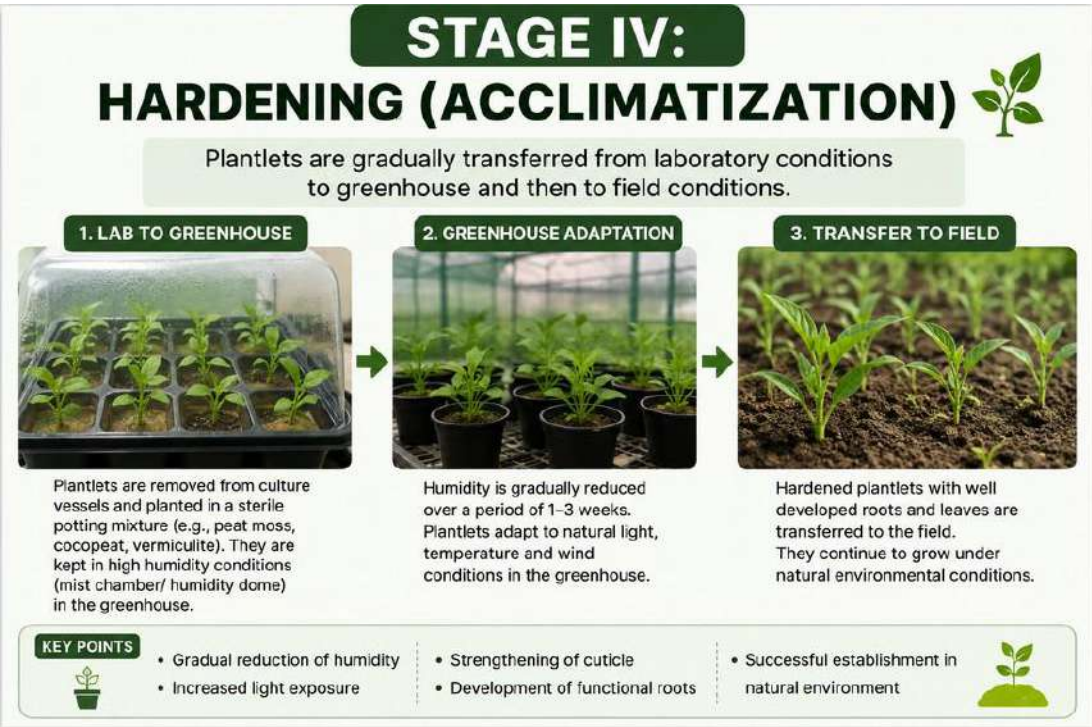
Plantlets produced in vitro are delicate and cannot survive directly under field conditions.

Procedure

- Removal of agar from roots.
- Transfer to sterilized potting mixture.
- Maintenance under high humidity and low light.
- Gradual exposure to normal environmental conditions.

Objective

- To acclimatize plantlets for field transplantation.



Applications of Micropropagation in Agriculture

Micropropagation has become an essential tool in modern agriculture for the rapid production of high-quality planting material. Its major applications include:

1. Rapid Mass Multiplication
   - Produces thousands to millions of plants from a single explant in a short time.
   - Ensures a continuous supply of planting material throughout the year.
2. Production of Disease-Free Plants
   - Meristem and shoot-tip culture eliminate viruses and other pathogens.
   - Healthy planting materials improve crop yield and quality.
3. Clonal Propagation of Elite Varieties
   - Maintains desirable traits such as high yield, disease resistance, and superior quality.
   - Produces genetically uniform (true-to-type) plants.
4. Propagation of Crops with Poor Seed Viability
   - Useful for crops that produce few seeds or have low

germination rates.

- Examples include banana, potato, sugarcane, and cassava.

5. Conservation of Germplasm
   - Preserves rare, elite, and endangered crop varieties under controlled conditions.

Supports long-term storage and breeding programs.

Applications of Micropropagation in Agriculture

Agricultural crop	Scientific name	Major agricultural importance
Banana	Musa spp.	Fruit production and rapid multiplication
Potato	*Solanum tuberosum*	Production of disease-free seed
Sugarcane	*Saccharum officinarum*	Rapid multiplication of healthy planting
Strawberry	*Fragaria × ananassa*	Production of disease-free planting
Sweet potato	*Ipomoea batatas*	Rapid multiplication of healthy vines
Cassava	*Manihot esculenta*	Production of disease-free planting
Pineapple	*Ananas comosus*	Large-scale production of
Ginger	*Zingiber officinale*	Production of disease-free
Turmeric	*Curcuma longa*	Rapid multiplication and disease-free
Taro	*Colocasia esculenta*	Rapid multiplication of healthy planting

Micropropagation in Medicinal Plants

Micropropagation is a modern plant tissue culture technique used for the rapid multiplication of plants under sterile and controlled laboratory conditions. It is particularly important for medicinal plants because many species have poor seed germination, slow growth, limited natural propagation, or are becoming rare due to excessive collection from the wild.

In micropropagation, a small piece of plant tissue called an explant is taken from a

healthy mother plant and sterilized. It is then cultured on a nutrient medium containing essential minerals, vitamins, sugars and plant growth regulators. Under controlled temperature, light and humidity, the explant develops into shoots. These shoots are multiplied through repeated subculturing. The individual shoots are then transferred to a rooting medium containing auxins such as IBA or NAA. After sufficient root development, the plantlets are gradually acclimatized to greenhouse and field conditions.

Several important medicinal plants can be propagated through tissue culture, including Ashwagandha (Withania somnifera), Sarpagandha (Rauvolfia serpentina), Aloe vera (Aloe barbadensis), Brahmi (Bacopa monnieri), Stevia (Stevia rebaudiana).

Applications in Medicinal Plants

Many medicinal plants are overexploited in nature. Micropropagation helps in their conservation and large-scale cultivation.

Table : Application in medicinal plant

Medicinal plant	Scientific name	Major medicinal importance
Ashwagandha	*Withania somnifera*	Adaptogenic and medicinal compounds
Aloe vera	*Aloe barbadensis*	Skin care and medicinal products
Sarpagandha	*Rauvolfia serpentina*	Source of reserpine
Stevia	*Stevia rebaudiana*	Natural sweetener
Neem	*Azadirachta indica*	Antimicrobial and insecticidal properties
Turmeric	*Curcuma longa*	Curcumin and anti-inflammatory uses
Ginger	*Zingiber officinale*	Digestive and medicinal uses
Brahmi	*Bacopa monnieri*	Traditionally used for memory and cognition
Isabgol	*Plantago ovata*	Dietary fibre and digestive health

Micropropagation in Forestry Crops

Micropropagation is a plant tissue culture technique used for the rapid multiplication of forest trees and other woody plants under sterile and controlled laboratory conditions. It is particularly useful in forestry because many tree species have long growth cycles, poor seed germination, seasonal seed production, or difficulty in conventional vegetative propagation.

In micropropagation, a small piece of plant tissue called an explant is collected from a healthy and superior mother plant. The explant is surface sterilized and placed on a suitable nutrient medium containing minerals, vitamins, sugar and plant growth regulators. The explant develops shoots, which are multiplied through repeated subculturing. The individual shoots are transferred to a rooting medium containing auxins such as IBA or NAA. Rooted plantlets are then gradually acclimatized and transferred to nursery and field conditions.

Table : Application in forestry crops

Forestry crop	Scientific name	Major forestry importance
Teak	*Tectona grandis*	High-quality timber and furniture
Eucalyptus	Eucalyptus spp.	Pulp, paper and timber production
Poplar	Populus spp.	Pulp, plywood and timber
Bamboo	Bambusa spp.	Construction, paper and handicrafts
Sandalwood	*Santalum album*	Valuable timber and fragrant heartwood
Acacia	Acacia spp.	Timber, fuelwood and pulp production
Neem	*Azadirachta indica*	Timber, fuelwood and agroforestry
Rosewood	*Dalbergia latifolia*	High-value timber and furniture
Paulownia	Paulownia spp.	Fast-growing timber and agroforestry
Casuarina	*Casuarina equisetifolia*	Fuelwood, poles and windbreaks

Micropropagation is highly useful for the rapid multiplication of elite forest trees with desirable characteristics such as fast growth, good timber quality, disease resistance and adaptability to environmental conditions. It can produce a large number of genetically uniform planting materials within a relatively short period. It is also valuable for the conservation of rare, endangered and economically important tree species.

Important forestry crops propagated through micropropagation include Eucalyptus (Eucalyptus spp.), Teak (Tectona grandis), Poplar (Populus spp.), Bamboo Bambusa spp.), Sandalwood (Santalum album), Acacia (Acacia spp.), Neem (Azadirachta indica), and Paulownia (Paulownia spp.)

Applications in Forestry Crops

Forestry species often have long generation cycles and poor seed viability.

Reference

1. Espinosa-Leal, C.A., Puente-Garza, C.A. & García-Lara, S. (2018). In vitro plant tissue culture: means for production of biological active compounds. Planta, 248, 1–18.
2. The recent review by Frontiers in Plant Science (2025) is also excellent for discussing the four practical stages and current improvements in explant initiation, shoot multiplication, rooting and acclimatization.
3. Moraes, R.M., Cerdeira, A.L. & Lourenço, M.V. (2021). Using Micropropagation to Develop Medicinal Plants into Crops. Molecules, 26(6), 1752.
4. Rout, G.R., Samantaray, S. & Das, P. (2000). In vitro manipulation and propagation of medicinal plants. Biotechnology Advances, 18(2), 91–120.
5. Thorpe, T. A., Harry, I. S., & Kumar, P. P. (1991). Application of Micropropagation to Forestry. In Micropropagation: Technology and Application. Kluwer Academic Publishers. A classic reference on the use of micropropagation in forest tree improvement
6. Espinosa-Leal et al. (2018), mentioned above, is also excellent because it discusses plant tissue culture and production of valuable bioactive compounds and secondary metabolites.
7. Cloning of medicinal plants through tissue culture—A review. Useful when discussing the importance of mass clonal propagation and uniform medicinal plant material.

Volume: 06 Issue No: 09

DEVELOPMENT OF TRAIT-SPECIFIC PULSE VARIETIES THROUGH CONVENTIONAL AND MARKER ASSISTED BREEDING

Article ID: AG-VO6-I09-122

Jitendra Kumar*, Debjyoti Sen Gupta, Umesh, Amit Kumar Sharma, and GP Dixit

Division of Crop Improvement, ICAR-Indian Institute of Pulses Research,

Kanpur-208024, U. P., India

*Corresponding Author : Jitendra Kumar

Abstract

Pulses are important for nutritional security, having a high amount of protein (21-25%) and other beneficial compounds/nutrient. Breeding efforts have ensured the development of several high-yielding varieties. However, changing environmental conditions and increasing demond of nutritional security have shaped an urgent need for breeding pulse varieties with special trait(s). These varieties provide distinct advantages over conventional varieties by improving not only crop productivity and stability under diverse production environments but also enhancing nutritional quality, farmer profitability, and resilience to climate change. During the past years, the use of conventional and advanced genomics tools with high-throughput phenotyping has accelerated the development of special trait varieties in several pulse crops. In this article, we have discussed a comprehensive overview of special trait varieties developed in major pulse crops.

Keywords: Pulse crops, Trait-specific breeding, Marker-assisted breeding, and Biofortification.

Introduction

Pulses belong to the family Leguminosae/Fabaceae, which are rich nutritionally and have the ability to fix atmospheric nitrogen into the soil, making them the best-suited crops for sustainable agriculture. Pulses were grown globally on 91.23 million hectares, producing about 97.07 million tonnes with an average productivity of around 1.064 t ha^{-1} in the year 2024 (FAOSTAT, 2026). According to FAOSTAT (2026), India is the world's leading producer of pulses, followed by Canada, Myanmar, China, and Australia. In India, pulse production was

27.41 MT based on the third estimate for 2025-26. Madhya Pradesh (5.35 MT) is the leading state in pulses production, followed by Maharashtra (5.08 MT), Rajasthan (4.47 MT), Uttar Pradesh (3.10 MT), and Gujarat (2.30 MT) (https://www.upag.gov.in/).

Breeding pulse varieties with special trait(s) may have one or specific characteristics including resistance to major diseases and insect pests, tolerance to drought, heat, salinity, herbicides, and waterlogging, early maturity, synchronous flowering, erect growth habit suitable for mechanical harvesting, enhanced biological nitrogen fixation, improved cooking quality, reduced antinutritional factors, and biofortification with essential micronutrients such as iron and zinc. Thus, these varieties provide distinct advantages over conventional varieties by improving not only crop productivity and stability under diverse production environments but also enhancing nutritional quality, farmer profitability, and resilience to climate change. During the past years, the use of conventional and advanced genomics tools with high-throughput phenotyping has accelerated the development of special trait varieties in several pulse crops. This article discussed development of trait-specific pulse varieties through conventional and marker assisted breeding.

Marker-assisted breeding (MAB)-derived varieties for specific traits in pulses

DNA marker technology has evolved from first to fifth-generation in pulse crops (Gupta *et al*., 2013; Kumar *et al*., 2020). These markers have been used to tag/map the genes/QTLs for several agronomically important traits in several pulses and identified tightly linked molecular markers with genes/QTLs controlling these traits. These markers have been used to develop trait-specific varieties in pulses.

Drought-tolerant variety of chickpea

Barmukh *et al*. (2022) identified a *QTL-hotspot* genomic region from the ICC 4958 accession that explained the major phenotypic variation (>50%) for drought tolerance. This *QTL-hotspot* genomic region has been used through a marker-assisted backcrossing (MABC) approach for enhancing drought tolerance in elite Indian chickpea.

- **Pusa Chickpea 10216:** This is the first drought-tolerant chickpea variety carries a drought-resistant QTL-hotspot region from the ICC 4958 genotype into the genetic background of the popular variety Pusa 372. The newly produced variety recorded an average grain yield of 1,447 kg ha^{-1}, which is more than 11% greater than the recurrent

parent Pusa 372. It weighs around 22.2 g per 100 seeds, has a lovely grain color, and matures in about 110 days.

- **IPCL 4-14: This is another drought-tolerant cultivar developed through marker-assisted breeding carrying** the same drought-resistant QTL-hotspot region from the ICC 4958 genotype into the genetic background of the popular desi variety DCP 92. This variety was released for cultivation in the North West Plain Zone of India. The newly produced variety recorded a grain yield of 1800-2000 q/ha kg ha^{-1} with a maturity of 130-135 days. This variety has a light brown colour of seed with a size of 16.6g/100 seeds and resistance to fusarium wilt, collar rot, stunt diseases, and is moderately tolerant to dry root rot.

Wilt resistance varieties of chickpea

- **Super Annigeri 1**: This chickpea variety developed MABC breeding by introducing a Fusarium wilt resistance genomic fragment from the donor genotype WR 315 into the genetic background of the well-known cultivar Annigeri 1. It has an average yield of 1,898 kg/ha, highly resistance to *Fusarium* wilt, a semi-upright growth habit with a 95-110 days to maturity and nice seed size with 18-20 g/100 seeds.
- **IPCMB 19-3 (Samridhi):** The molecular SSR markers tightly linked with the gene controlling resistance to *foc2* used to develop a **desi chickpea variety IPCMB19-3 (Samriddhi) for** cultivation in the **Central Zone of India**. The average grain yield of this variety was reported to be 20.8 q/ha under irrigated and drought-stress conditions and has a large seed size (24.1 g/100 seeds). The protein content is approximately 22.9% and matures in about 106 days. This is suitable for cultivation in both rainfed and irrigated production systems.

Bio-fortified pulses varieties

Deficiencies in nutrition among humans occur due to lack of availability of food and inadequate macro- and micro-nutrition in the diet that includes proteins, lipids, vitamins and minerals, resulting in protein deficiency. Genetic biofortification is an important strategy for addressing micronutrient deficiencies in human populations. This is achieved by incorporating favourable alleles or modifying the genetic constitution of crop varieties to improve their nutritional quality while maintaining desirable agronomic traits. During the past years,

conventional breeding approaches have developed several biofortified varieties in pulses, which have been discussed below.

- **IPC 2005-62 variety of chickpea**: This biofortified variety of chickpea having protein content (26.47%) has recommended for cultivation in Uttar Pradesh. This small seeded (15.2g/100 seeds) variety has good resistance to Fusarium wilt. It performs well under late-sown irrigated conditions, making it a suitable choice for farmers seeking higher productivity and better grain quality under late-sown conditions. It takes approximately 120-125 days for complete maturity and produces an average yield of 18-20 quintals per hectare under good crop management practices.
- **IPL 220 variety of lentil**: This biofortified high-yielding lentil variety has high Iron (Fe) 73-114 ppm and Zinc (Zn) 51-63 ppm, and is suitable for cultivation in the North Eastern Plain Zone and Central Zone of India. This variety matures in about 115-120 days and has an average yield potential of 18-20 quintals per hectare under good management. It is a small-seeded and orange cotyledon variety with good cooking quality and high consumer preference. IPL 220 is a popular choice among lentil farmers.

Mechanically harvestable varieties

Timely harvesting, high labour cost, and shortage of labour at the time of harvesting have increased the demand for mechanically harvestable varieties in pulses. Breeding efforts have been concentrated on creating cultivars that are appropriate for automated harvesting by combining several traits, including erect and compact plant architecture, uniform maturity, increased initial pod height (≥20 to 25 cm), resistance to lodging and pod shattering suitable to mechanical harvesting. This resulted in the development of the following varieties in pulses.

- **IPC 2015-132 (Kundan) of chickpea**: This mechanical-harvestable variety of was developed by interspecific hybridization between GNG 1581 (Cicer arietinum) and ILWC 21 (Cicer reticulatum). This variety has all those traits, including tall with erect growth habit, which are suitable for mechanical harvesting. It has resistance against Fusarium wilt and is moderately resistant to dry root rot, collar rot, and stunt diseases. Its seeds are small in size (14.7g/100 seed weight) with brown seed colour and mature in 128 days.
- **CO-9 (COGG 13-19) variety of green gram**: This mechanically harvestable variety of green gram was developed by Tamil Nadu Agriculture University, Coimbatore through

pedigree method. It was developed from a crossing between CO6 and COGG912 genotypes of chickpea and released for cultivation in the Southern Zone of India. Breeding for specific traits like synchronous maturity and determinate plant type makes this variety suitable for mechanical harvesting. Besides, it is moderately resistant to YMD, has shiny and medium bold seeds (4.0 to 4.5 g/100) and 23.2% protein content. It has 8.25 q/ha yield potential and matures within 65-70 days.

Early maturing varieties

Early maturity is an important trait for developing climate-resilient varieties for rainfed and drought-prone conditions. The breeding efforts have developed several early-maturing varieties in pulses carrying the above specific traits.

- **IPM 205-7 (Virat) variety of mungbean**: This is an extra-early maturing mungbean has 52-55 days maturity, which enables farmers to increasing the dropping intensity in cereal based cropping systems (rice-wheat and rice-rice). This provides extra income to farmers in a short period of time. It has large, shiny, and bright green seeds with an average yield of 12-14 quintal/hectare. This helps to secure food and nutrition in India.
- **Pusa Ageti Masoor (L 4717) variety of lentil**: This is extra-early lentil variety recommended for cultivation in the Central Zone of India. It has approximately 13 q/ha yield potential, and it matures in about 100 days. As it is an early variety, farmers can use it in multiple cropping to increase cropping intensity and farm income.

Green-seeded varieties of pulses

Immature pods or fresh green and soft seeds of pulses are consumed as vegetables. Therefore, breeding efforts have been made to develop several pulse varieties having green color of dry grains.

- **IPFD 10-12 of field pea**: This is the green-seeded field pea variety developed through the conventional pedigree method of selection. This variety is more popular among farmers due to its green seeds, which enable it to be eaten in the off-season without any special preservation like cryopreservation, etc and it contains about 22.5% protein. It is recommended for cultivation in the Central Zone of India. It has resistance to powdery mildew, dwarf type, and green seeds, and it matures within 110-115 days and possesses yield potential of about 21-22 q/ha.

- **IPF 16-13 (Harit) of field pea**: Harit is another green-seeded field pea for cultivation in Eastern UP, Bihar, Jharkhand, WB, Assam and some other plain regions of NE states. It is a tall variety with a leafy growth habit and round seeds. It is resistant to powdery mildew and moderately tolerant to rust disease, and yield potential 18-20 quintal/hectare yield with 115-120 days maturity.
- **Pusa Green 112 of chickpea:** This is the green-seeded desi chickpea variety developed through conventional pedigree breeding method. It is recommended for cultivation in the North Western Plain Zone (NWPZ) of India. Its seeds are green in color. It has tolerance to drought stress and resistance to multiple races of Fusarium wilt with a yield potential of 22 q/ha and 145-148 days maturity.

References

1. Barmukh, R., Roorkiwal, M., Dixit, G. P., Bajaj, P., Kholova, J., Smith, M. R., et al. 2022. Characterization of 'QTL-hotspot'introgression lines reveals physiological mechanisms and candidate genes associated with drought adaptation in chickpea. Journal of Experimental Botany, 73(22), 7255-7272.
2. FAOSTAT (2026). https://www.fao.org/faostat/en/#data/QCL. 10 July, 2026.
3. Gupta, P. K., Rustgi, S., and Mir, R. R. 2013. Array-based high-throughput DNA markers and genotyping platforms for cereal genetics and genomics. In Cereal genomics II (pp. 11-55). Dordrecht: Springer Netherlands.
4. Kumar, S., Kumar, M., Mir, R. R., Kumar, R., and Kumar, S. 2020. Advances in molecular markers and their use in genetic improvement of wheat. In Physiological, molecular, and genetic perspectives of wheat improvement (pp. 139-174). Cham: Springer International Publishing.

Volume: 06 Issue No: 09

CULTIVATION OF KARONDA AND ITS BENEFITS TO FARMERS IN RAJASTHAN

Article ID: AG-VO6-I09-123

***D.L. Bagdi and Purushotam Sharma**

Department of Plant Physiology, S.K.N. College of Agriculture, Jobner, Rajasthan-303329, India

Department of Entomology, S.K.N. College of Agriculture, Jobner, Rajasthan-303329, India

*Corresponding Author : D.L. Bagdi

Introduction

Karonda (*Carissa carandas* L.) is a hardy, evergreen, thorny fruit shrub belonging to the family Apocynaceae. It is an important minor fruit crop grown in the arid and semi-arid regions of India, including Rajasthan. Karonda is valued for its drought tolerance, medicinal properties, and use in pickles, jams, jellies, squashes, and candies.

Climate

- Best suited to tropical and subtropical climates.
- Can tolerate high temperatures (up to **45°C**) and drought.
- Annual rainfall requirement: **400–1,000 mm**.
- Performs well under rainfed conditions.

Soil

- Grows in a wide range of soils, including sandy, loamy, and rocky soils.
- Well-drained soil is ideal.
- Tolerates saline and alkaline soils.
- Optimum soil pH: **6.5–8.0**.

Popular Varieties

- Pant ManoharPant SudarshanKonkan Bold
- CHES Karonda selectionsLocal Rajasthan types

Propagation

- SeedsStem cuttingsAir layeringBudding (preferred for true-to-type plants)

Planting

- **Best planting time:** July–August (monsoon)
- **Pit size:** 60 × 60 × 60 cm
- **Spacing:** 3 × 3 m or 4 × 4 m
- Fill pits with topsoil mixed with **10–15 kg FYM** before planting.

Nutrient Management

- Apply **10–20 kg FYM** per plant annually.
- Apply recommended doses of **NPK fertilizers** based on plant age and soil test results.
- Micronutrient application improves fruit yield and quality where deficiencies occur.

Irrigation

- Water regularly during establishment.
- Mature plants require only occasional irrigation during prolonged dry periods.
- Avoid waterlogging.

Weed Management

- Keep the orchard weed-free during the initial years.
- Mulching helps conserve moisture and suppress weeds.

Training and Pruning

- Remove weak, diseased, and crossing branches.
- Light annual pruning after harvest encourages healthy growth and fruiting.

Pest and Disease Management

Common pests:

- Fruit borerAphidsMealybugs

Common diseases:

- Leaf spotAnthracnose

Use integrated pest management (IPM), orchard sanitation, and need-based plant protection measures.

Harvesting

- Plants begin bearing fruits in **2–3 years** after planting.
- Fruits are harvested when they change from **green to pink, crimson, or dark purple**, depending on the intended use.
- Harvesting season in Rajasthan is generally **May to July**.

Yield

- A mature plant produces **20–50 kg of fruits per year**, depending on variety and management.
- Average orchard yield ranges from **8–15 tonnes per hectare**.

Uses

- Fresh consumption (ripe fruits)PicklesJam and jelly
- Syrup and squashCandy and chutneyTraditional medicinal preparations

Importance of KarondaCultivation

1. **Suitable for Arid and Semi-Arid Regions**
    - Highly tolerant to drought, heat, and dry climatic conditions.
    - Performs well under rainfed farming with limited irrigation.
2. **Utilization of Marginal Lands**
    - Grows successfully in poor, rocky, saline, and alkaline soils.
    - Makes productive use of wastelands and degraded lands.
3. **Low Cost of Cultivation**
    - Requires less irrigation, fertilizers, and plant protection measures.
    - Easy to maintain, making it suitable for small and marginal farmers.
4. **High Economic Value**
    - Fruits have good market demand for fresh consumption and processing.
    - Value-added products such as pickles, jams, jellies, syrups, squashes, candies, and chutneys increase farmers' income.
5. **Nutritional Importance**
    - Rich source of **vitamin C**, **iron**, **calcium**, **phosphorus**, and dietary fibre.
    - Contains natural antioxidants that promote good health.
6. **Medicinal Value**
    - Used in traditional medicine for treating anaemia, digestive disorders, fever, and skin ailments.
    - Fruits and leaves possess antioxidant, antimicrobial, and anti-inflammatory properties.
7. **Environmental Benefits**
    - Prevents soil erosion and conserves moisture.

- Suitable for dryland horticulture and agroforestry systems.
- Improves biodiversity in arid ecosystems.

8. **Excellent Live Fence**
   - Dense, thorny shrubs form an effective natural barrier around fields and orchards.
   - Protects crops from grazing animals and intruders.
9. **Climate-Resilient Crop**
   - Can withstand high temperatures and prolonged dry spells.
   - Well suited to climate change adaptation in water-scarce regions.
10. **Employment Generation**
    - Creates opportunities in fruit harvesting, processing, packaging, transportation, and marketing.
    - Supports rural entrepreneurship through small-scale processing industries.

Fruit Quality of Karonda: Karonda (*Carissa carandas*) is a hardy fruit crop valued for its high nutritional content, medicinal properties, and suitability for processing. The quality of its fruits depends on cultivar, stage of maturity, climate, soil, and crop management practices.

1. Physical Characteristics

- Fruits are small, round to oval, and borne in clusters.
- Average fruit weight ranges from **3–10 g** depending on the variety.
- The skin is smooth and glossy.
- Fruit colour changes from **green → pink → crimson → dark purple or black** at full maturity.
- The pulp is juicy with **2–8 small seeds**.

2. Chemical Composition

- **Total Soluble Solids (TSS):** 8–14 °Brix
- **Acidity:** 2–5% (high in unripe fruits, decreases on ripening)
- **Vitamin C:** 20–40 mg per 100 g pulp
- **Sugars:** Increase during ripening, improving sweetness.
- Rich in **iron, calcium, phosphorus, potassium**, and dietary fibre.
- Contains natural antioxidants such as **anthocyanins, flavonoids, and phenolic compounds**.

3. Nutritional Quality

Karonda is considered a highly nutritious fruit because it:

- Is an excellent source of **vitamin C**.
- Contains appreciable amounts of **iron**, helping prevent anaemia.
- Provides antioxidants that protect against oxidative stress.
- Is rich in fibre, promoting digestive health.
- Supplies essential minerals for normal body functions.

4. Sensory Quality

- **Unripe fruits:** Sour, highly acidic, and firm.
- **Half-ripe fruits:** Slightly sour and suitable for pickles.
- **Fully ripe fruits:** Sweet-tart flavour with attractive dark purple colour and pleasant aroma.
- Ripe fruits are preferred for **jams, jellies, squash, syrups, and beverages**.

5. Processing Quality

Karonda is an excellent processing fruit because it:

- Has high acidity and pectin content, making it ideal for **jelly and jam preparation**.
- Produces attractive natural colour in processed products.
- Retains flavour well during processing.
- Has good shelf life when processed into value-added products.

6. Factors Affecting Fruit Quality

- Variety or cultivar
- Proper irrigation and drainage
- Balanced fertilization, especially potassium
- Adequate sunlight
- Timely harvesting at the appropriate maturity stage
- Effective pest and disease management

7. Indicators of Good Quality Karonda Fruits

- Uniform size and shape
- Bright, glossy skin
- Deep purple or black colour at full ripeness
- Firm but juicy pulp

- High TSS with balanced acidity
- Free from cracks, bruises, insect damage, and diseases

Conclusion

Karonda is a profitable and climate-resilient fruit crop for Rajasthan. Its adaptability to harsh environmental conditions, low input requirements, nutritional value, and strong market demand for fresh and processed products make it an excellent choice for farmers in arid and semi-arid regions.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article.

Competing interests: The authors declare that they have no competing interests.



Volume: 06 Issue No: 09

CULTIVATION OF KER AND ITS BENEFIT TO FARMERS IN RAJASTHAN

Article ID: AG-VO6-I09-124

***D.L. Bagdi and S.P. Singh**

Department of Plant Physiology, S.K.N. College of Agriculture, Jobner, Rajasthan-303329, India

Department of Horticulture, S.K.N. College of Agriculture, Jobner, Rajasthan-303329, India

*Corresponding Author: D.L. Bagdi

Introduction

Ker (*Capparis decidua*), locally known as Ker or Kair, is an important indigenous fruit-bearing shrub of the hot arid and semi-arid regions of Rajasthan. It is highly drought-tolerant and naturally grows in the Thar Desert. Ker fruits are widely used for making pickles and the famous **Ker-Sangri** vegetable, providing an important source of income for rural communities.

Climate

- Performs best in well-drained soils with pH **7.0–9.0**.

Propagation

- By seeds.
- By stem cuttings.
- Vegetative propagation (budding/grafting) is preferred for obtaining uniform, high-yielding plants.

Planting

- Best planting time: **July–August** (monsoon season).
- Pit size: **60 × 60 × 60 cm**.
- Spacing: **4–5 m × 4–5 m**.

Nutrient Management

- Apply **10–15 kg well-decomposed farmyard manure (FYM)** per plant annually.
- Apply recommended doses of nitrogen, phosphorus, and potassium according to plant age and soil fertility.

Irrigation

- Irrigation is generally required only during establishment.
- Mature plants can survive under rainfed conditions because of their deep root system.

Weed and Pest Management

- Keep the field weed-free during the first two years.
- Ker has relatively few serious insect pests and diseases, making it a low-maintenance crop.

Harvesting

- Plants begin bearing fruits in **3–4 years**.
- Immature green fruits are harvested mainly during **April–June** for pickling and processing.

Benefits of Ker

1. **Excellent drought tolerance**, making it ideal for Rajasthan's arid regions.
2. **Provides additional income** through the sale of fresh fruits, pickles, and processed products.
3. **Rich in nutrients and antioxidants**, contributing to a healthy diet.
4. **Medicinal value**: Traditionally used for digestive disorders and various other ailments.
5. **Controls soil erosion** by stabilizing sand dunes and improving degraded lands.
6. **Useful as a biofence** due to its thorny growth habit.
7. **Provides fodder, fuelwood, and small timber** for rural households.
8. **Suitable for wastelands**, requiring very little water and maintenance.
9. **Supports biodiversity** and serves as an important species in desert ecosystems.

Importance of KerCultivation

1. **Suitable for Arid Regions**
    - Thrives in areas receiving only **100–400 mm** annual rainfall.
    - Can withstand extreme temperatures (up to **48°C**) and prolonged drought.
2. **Efficient Use of Wastelands**
    - Grows well in sandy, saline, alkaline, and degraded soils.
    - Converts unproductive land into a source of income.
3. **Low Input Requirement**
    - Requires very little irrigation after establishment.

- Needs minimal fertilizers and plant protection measures.
- Suitable for rainfed farming.

4. **Income Generation**
   - Immature green fruits are in high demand for pickles and processed products.
   - Provides additional income to farmers through fresh and processed fruit sales.
   - Supports cottage and food-processing industries.
5. **Nutritional Value**
   - Fruits contain vitamins, minerals, dietary fiber, and antioxidants.
   - Contribute to a healthy diet and food security in dry regions.
6. **Medicinal Importance**
   - Used in traditional medicine for digestive disorders, cough, fever, skin ailments, and inflammation.
   - Various plant parts have antioxidant and antimicrobial properties.
7. **Environmental Benefits**
   - Prevents soil erosion and stabilizes sand dunes.
   - Improves biodiversity in desert ecosystems.
   - Acts as a windbreak and shelterbelt.
8. **Supports Livestock**
   - Leaves and tender shoots serve as fodder during drought periods.
   - Woody branches are used as fuelwood.
9. **Climate-Resilient Crop**
   - Well adapted to climate change due to its exceptional drought and heat tolerance.
   - Ensures stable production under harsh environmental conditions.
10. **Export and Market Potential**
    - Processed Ker products, especially pickles and **Ker-Sangri**, have strong domestic and international demand.
    - Offers opportunities for value addition and export-oriented entrepreneurship.

Fruit Quality of Ker: Fruit quality refers to the physical, chemical, nutritional, and sensory characteristics that determine the market value and consumer acceptance of Ker fruits. The quality of Ker fruits is influenced by variety, climate, soil, maturity stage, and cultivation practices.

1. Physical Characteristics

- **Fruit type:** Berry
- **Shape:** Round to oval
- **Colour:** Green when immature; reddish-orange to red when fully ripe
- **Size:** Approximately **0.8–1.5 cm** in diameter
- **Weight:** About **0.5–2.0 g** per fruit
- **Texture:** Firm and smooth when immature

2. Chemical Characteristics

- **Total Soluble Solids (TSS):** 8–14 °Brix
- **Acidity:** Moderate, giving a pleasant tangy taste
- **pH:** Approximately 4.5–5.5
- **Vitamin C:** Good source of ascorbic acid
- **Phenolic compounds:** Rich in natural antioxidants

3. Nutritional Quality

Ker fruits contain:

- Vitamin C Dietary fibre, Calcium, Iron and Potassium
- Phosphorus, Natural antioxidants and flavonoids

These nutrients enhance the nutritional value of Ker and contribute to health benefits.

4. Sensory Quality

- Mildly bitter and astringent when fresh
- Pleasant flavour after processing
- Excellent texture for pickles
- Characteristic aroma highly preferred in traditional Rajasthani cuisine

5. Processing Quality

Immature green fruits are preferred because they:

- Have firm texture
- Retain shape during processing
- Absorb spices effectively
- Produce high-quality pickles

6. Factors Affecting Fruit Quality

- Genetic variation (variety)

- Climatic conditions
- Soil fertility
- Irrigation practices
- Harvesting stage
- Post-harvest handling and storage

7. Indicators of Good Quality Ker Fruits

- Uniform green colour
- Medium-sized fruits
- Firm and smooth texture
- Free from insect and disease damage
- Fresh appearance with no shrivelling
- High vitamin C and antioxidant content

Conclusion: Ker is one of the most valuable indigenous fruit crops of Rajasthan. Its ability to thrive under extreme drought, low input requirements, nutritional and medicinal importance, and high market demand for value-added products such as pickles make it an excellent crop for sustainable farming and livelihood improvement in the arid regions of the state.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

INSECT SOUNDS AS CROP CLUES: USING BIOACOUSTICS TO MONITOR AGRICULTURAL INSECTS

Article ID: AG-VO6-I09-125

Aarthi S

Assistant Professor, Department of Agriculture Entomology, Adhiparasakthi Horticulture College, Kalavai, Tamil Nadu, India.

Abstract

Agricultural fields are filled with an acoustic world that often remains unnoticed by humans. Insects produce sounds and vibrations during communication, movement, feeding and mating, creating biological signals that can potentially be used for crop monitoring. Bioacoustics—the recording and analysis of biological sounds-is emerging as a promising tool for detecting and monitoring agricultural insects. Advances in microphones, vibration sensors, digital signal processing and artificial intelligence are making it possible to automatically analyse large volumes of acoustic information. Such systems may help detect hidden pests, monitor insect populations, identify pest activity and provide early warnings of potential outbreaks. However, background noise, species with similar acoustic signals, limited field datasets and the need for validation remain important challenges. Integrating bioacoustics with conventional insect trapping, field scouting, weather data and remote sensing could strengthen integrated pest management. Listening to insects may therefore become an important component of precision and sustainable agriculture.

Keywords: Bioacoustics; Agricultural insects; Pest monitoring; Insect sounds; Integrated pest management

Introduction

Agricultural ecosystems are dynamic environments in which insects continuously interact with crops, natural enemies, plants and other organisms. Farmers and entomologists traditionally monitor these interactions through visual scouting, sweep nets, light traps, pheromone traps and direct examination of crop damage. These methods remain fundamental to insect pest

management. However, many insects spend part of their life cycle hidden inside plants, fruits, stems, wood or stored agricultural commodities, making visual detection difficult.

An emerging approach offers a different way of observing these hidden activities: **listening to insects**.

Bioacoustics refers to the study and application of sounds and vibrations produced by living organisms. In entomology, acoustic signals may originate from communication, mating, courtship, movement, feeding, flight or defensive behaviour. Crickets and katydids are well-known examples of sound-producing insects, while grasshoppers and cicadas generate characteristic signals using specialised body structures. Even insects that do not produce prominent airborne sounds can create vibrations that travel through plants, wood or stored products.

Recent advances in recording technology and machine learning have increased interest in automated insect acoustic monitoring. Such technologies have the potential to transform insect surveillance from occasional manual observations into continuous digital monitoring.

The fundamental idea is simple:

If insects leave acoustic clues, technology may be able to detect and interpret those clues.

THE ACOUSTIC WORLD OF AGRICULTURAL INSECTS

An agricultural field can be considered a complex biological soundscape. Different organisms contribute different acoustic signals, creating a mixture of sounds that changes according to time, weather, season and habitat.

Insects produce sounds through several mechanisms. Crickets and katydids commonly produce sounds through **stridulation**, where specialised structures are rubbed against each other. Grasshoppers may generate sounds through interactions between their legs and wings, while cicadas produce powerful signals using specialised tymbal structures.

In addition to intentional communication, insects may produce sounds during feeding, walking, flying and movement within concealed environments. The acoustic characteristics of an insect signal may include frequency, pulse duration, repetition rate, amplitude and temporal pattern. These characteristics can provide useful information for distinguishing among species or identifying insect activity. This creates the possibility of developing an **acoustic fingerprint** for selected agricultural insects.

FROM INSECT SOUNDS TO DIGITAL INFORMATION

To the human ear, an insect call may sound like a simple chirp, buzz or clicking noise. A computer, however, can convert the recording into numerical data. One important tool is the **spectrogram**, which represents changes in frequency and intensity over time. Researchers can examine these patterns to identify characteristic signals.

Modern machine-learning techniques can be trained using recordings from known insect species. Once trained, the system can analyse new recordings and estimate which insect or acoustic pattern is present. Automated bioacoustic research has expanded rapidly. A systematic review published in 2024 examined automated bioacoustic models used to detect, classify and monitor insects and highlighted the growing role of machine learning in this field.

However, successful identification under controlled conditions does not necessarily guarantee equal performance in agricultural fields. Real farms contain wind, rain, machinery, birds, frogs and numerous other insects. Therefore, reliable agricultural applications require field-based datasets and robust signal-processing methods.

SMART TRAPS THAT LISTEN

Traditional insect traps require periodic human inspection. A smart trap could potentially combine a conventional trapping mechanism with a camera, microphone or vibration sensor. Such a system could record insect activity automatically and transmit the data to a digital platform.

The basic workflow could be:

Sensor → Recording → Signal processing → Insect recognition → Population trend → Alert

If the system detects an increasing acoustic signal associated with a target pest, it could notify the farmer or agricultural professional that closer field inspection is required. This approach could reduce the burden of manually checking large numbers of traps. Importantly, a bioacoustic alert should not automatically mean that pesticide application is required. Instead, it should trigger **verification and informed decision-making**.

BIOACOUSTICS AND INTEGRATED PEST MANAGEMENT

Integrated Pest Management (IPM) is based on monitoring pest populations and selecting appropriate management strategies according to economic and ecological considerations. Bioacoustics could become one additional monitoring layer within IPM.

A future system could combine:

Acoustic data + pheromone traps + weather information + crop stage + field scouting + remote sensing to generate a more complete picture of pest activity.

The objective should be:

Detect early → Verify → Assess risk → Select appropriate management

LISTENING TO BENEFICIAL INSECTS

Farms are also home to pollinators, predators, parasitoids and decomposers. Bees, for example, generate characteristic sounds during flight, and acoustic monitoring has been investigated as a tool for insect detection and ecological assessment. Monitoring insect soundscapes could therefore contribute to studies of agricultural biodiversity. However, acoustic diversity should not be interpreted as a direct measure of ecosystem health without supporting evidence. A loud pest population could increase acoustic activity while simultaneously causing serious crop damage.

Therefore, future systems should aim to identify **which organisms are producing the sounds**, rather than simply measuring how much sound is present.

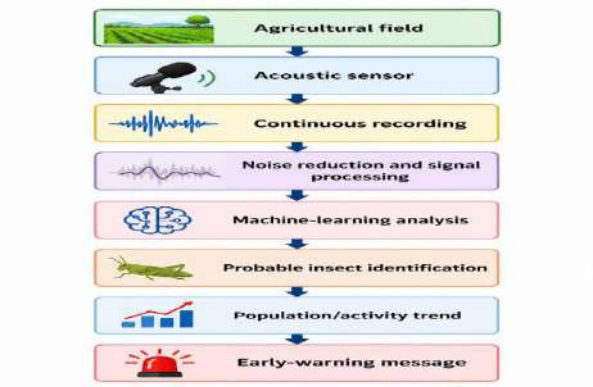
ARTIFICIAL INTELLIGENCE: THE DIGITAL EAR

This approach transforms acoustic recordings into potentially useful agricultural information. However, AI models depend heavily on the quality and diversity of their training data. Models developed from laboratory recordings may perform poorly when exposed to wind, rain, machinery and unfamiliar insect communities.

CAN SOUND PREDICT A PEST OUTBREAK?

This is one of the most exciting possibilities.

Suppose a particular pest produces increasing acoustic activity before its population reaches damaging levels. If this relationship is consistently observed, acoustic information could potentially become an early-warning indicator.



Future forecasting models could combine: Acoustic activity, Temperature, RH, Rainfall, Crop growth stage, Previous pest incidence, Pheromone-trap counts, Remote-sensing information. A model could then estimate pest risk as low, moderate or high.

Such a prediction would not guarantee an outbreak. Instead, it would help direct attention to areas where additional scouting is most valuable. In this way, agriculture could move from **reactive detection to earlier surveillance**.

THE FUTURE OF INSECT SOUND MONITORING

The next generation of agricultural monitoring could integrate multiple technologies. Imagine a field equipped with smart insect traps, acoustic sensors and weather stations. Drones periodically survey the crop, while satellite imagery provides information about larger landscape patterns. Farmers use smartphones to report unusual insects, and entomologists validate difficult observations. All these data streams could be combined through an intelligent monitoring platform. The result would be a form of **digital entomological surveillance**.

India has particularly strong potential for this approach because of its diverse crops, climates and insect communities. Indian research has already highlighted opportunities for expanding insect bioacoustic research across additional taxonomic groups and ecosystems. Developing regional acoustic libraries for important agricultural pests, predators and pollinators could be an important step towards practical applications.

Conclusion

Agricultural insects communicate, move, feed and interact within a complex acoustic environment. Although much of this world remains beyond ordinary human perception, modern sensors can capture these signals and digital technologies can help interpret them. Bioacoustics has the potential to contribute to early pest detection, concealed-insect monitoring, biodiversity assessment and integrated pest management. When combined with artificial intelligence, smart traps, weather information and field scouting, acoustic monitoring could become an important component of precision agriculture.

Nevertheless, the technology is still developing. Reliable field datasets, standardised recording methods, species-specific acoustic libraries and extensive validation are required before broad agricultural deployment. The future is therefore not about replacing the entomologist with a microphone.

It is about giving the entomologist another sense. A sensor may hear what the human eye cannot see. An algorithm may detect a pattern that would take hours to identify manually. And a farmer may receive an early warning before a hidden pest becomes a visible problem. The agricultural field of tomorrow may not only be observed.

References

Kohlberg A.B., Myers C.R., Figueroa L.L. 2024. From buzzes to bytes: A systematic review of automated bioacoustics models used to detect, classify and monitor insects. *J Appl Ecol*. 61: 2190–2207. doi:10.1111/1365-2664.14630.

Mankin R.W., Hagstrum D.W., Smith M.T., Roda A.L., Kairo M.T.K. 2011. Perspective and promise: A century of insect acoustic detection and monitoring. *American Entomologist*. 57:30–44.

Tiwari C., Diwakar S. 2026. Bioacoustics research on insects in India: Current status and future directions. *Indian Journal of Entomology*. 88(2):497–505.

Nansen C, *et al*. 2020. Automatic detection and monitoring of insect pests—A review. *Agriculture*. 10:161.

Potamitis I, Rigakis I, Fysarakis K. 2015. The electronic McPhail trap: An insect trap that uses low-power cameras to automatically identify and count pests. *J Appl Entomol*.

Mankin RW, *et al*. 2023. Developments in crop insect pest detection techniques: Sound- and vibration-sensors for pest detection. Burleigh Dodds Science Publishing.

Volume: 06 Issue No: 09

TRANSGENIC AND GENOME-EDITED CROPS ON THE THRESHOLD OF THE FIELD

Article ID: AG-VO6-I09-126

[1]Deiva Prakash V, [1]Akshay K, [1]Swapnajit Behera, [1] Afrin Frank B S,

[1] Keshav Meena, [2] Sivaji M

[1]UG Student, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu 606 753, India

[2]Teaching Assistant Agricultural Biotechnology, Agricultural College and Research Institute, Vazhavachanur, Tiruvannamalai, Tamil Nadu 606 753, India

Corresponding Author: Deiva Prakash V

Introduction

Genetic technology in Indian and global agriculture has quietly split into two distinct regulatory tracks. The first — classical transgenics, where foreign DNA from bacteria or other species is inserted into a crop genome — remains the slower, more contested track: after 24 years, Bt cotton is still India's only commercially released transgenic crop, and GM mustard (DMH-11) sits in judicial limbo despite regulatory clearance. The second — genome editing (SDN1/SDN2 CRISPR-Cas techniques that alter a plant's own DNA without inserting foreign genes) — has moved with striking speed: India exempted these techniques from GMO biosafety rules in 2022, and by May 2025 had released two genome-edited rice varieties, DRR Dhan 100 (Kamala) and Pusa DST Rice 1, becoming the first country in the world to commercialise gene-edited rice. This assignment argues that the determining variable for whether a crop reaches a farmer's field is no longer scientific readiness or even yield benefit, but which regulatory track a given trait modification is classified under — a phenomenon this paper terms the Regulatory-Readiness Gap.

Two Technologies, One Word: Why 'Gm Crop' Is Misleading

Public and even policy discussion in India routinely uses "GM crop" as a single catch-all category. This is now analytically misleading, because two biologically and legally distinct

Two Technologies, One Word: Why 'Gm Crop' Is Misleading

Public and even policy discussion in India routinely uses "GM crop" as a single catch-all category. This is now analytically misleading, because two biologically and legally distinct technologies are in play.

Transgenics (Classical Genetic Modification)

A transgenic crop carries DNA transferred from an unrelated organism — typically a soil bacterium — into the plant genome. Bt cotton, for instance, carries a gene from Bacillus thuringiensis that produces an insecticidal protein, while GM mustard's DMH-11 carries the barnase and barstar genes from Bacillus amyloliquefaciens to enable hybrid seed production. Because foreign DNA crosses a species boundary, transgenics fall squarely under India's GMO biosafety regime — the Environment (Protection) Act, 1986, administered through the Genetic Engineering Appraisal Committee (GEAC) under the Ministry of Environment, Forest and Climate Change (MoEFCC), with food-safety oversight from the FSSAI under the Food Safety and Standards Act, 2006.

Genome Editing (CRISPR-Cas, SDN1/SDN2)

Genome editing uses tools such as CRISPR-Cas9 to make precise changes — deletions or small edits — within a plant's own existing DNA sequence, without introducing any foreign gene. India's Department of Biotechnology and MoEFCC, following global regulatory trends, exempted Site-Directed Nuclease 1 and 2 (SDN1/SDN2) edits from the GMO biosafety framework in 2022, treating them as functionally equivalent to conventional mutation breeding. This single classification decision, more than any scientific breakthrough, is why India's newest crop products reached farmers within roughly seven years of a national research programme rather than the two-decades-plus timeline typical of transgenic approval.

Transgenic = foreign DNA inserted → full GEAC/biosafety review.
Genome-edited (SDN1/SDN2) = native DNA edited, no foreign gene → exempt from GMO biosafety rules in India since 2022.

The same yield or stress-tolerance outcome can therefore face radically different regulatory timelines depending purely on the technique used to achieve it.

India's Transgenic Crops: Status As Of 2026

1. Bt Cotton — The Only Fully Commercialised Transgenic Crop

Approved for commercial cultivation in 2002, Bt cotton remains, in 2026, the only transgenic crop India has released to farmers without restriction. It now covers the overwhelming majority of India's cotton area, with adoption rates historically cited near 94 percent among cotton-growing farmers, and India ranks fifth globally by area under biotech crop cultivation — entirely on the strength of this single crop. Its two-decade run also means the underlying Bollgard-II event is agronomically ageing, with pink bollworm resistance emerging in parts of central India — a point often raised in seminar discussions of India's technology stagnation.

2. GM Mustard (DMH-11) — Cleared but Judicially Frozen

DMH-11, developed at Delhi University's Centre for Genetic Manipulation of Crop Plants, received GEAC's environmental-release approval — the regulatory milestone that would make it India's first GM food crop. Its barnase-barstar system enables hybrid mustard seed production in a normally selfpollinating crop, targeting higher oilseed yields and reduced edible-oil import dependence. Commercial rollout, however, remains stayed pending Supreme Court proceedings, with petitioners citing concerns over herbicide-



Figure 1. GM Mustard — flowering field

tolerant cultivation practices. The Government of India has told the Court that GM mustard would make edible oil more affordable and reduce import dependence — but the case remains unresolved as of mid-2026, nearly a decade after GEAC's first approval attempt in 2017.

3. Bt Brinjal — Fifteen Years Under Moratorium

GEAC approved Bt brinjal in 2009–10, but the then Environment Minister imposed an indefinite moratorium in February 2010 citing biosafety and socio-economic concerns. Only limited research trials have proceeded since. The moratorium is a useful comparative case (see the Global Landscape section) because Bangladesh commercialised the same trait in 2013 and the Philippines briefly did in 2022, giving India a rare opportunity to observe a genetically near-identical crop's real-world performance in neighbouring regulatory systems before deciding its own course.

4. The Pipeline: More Than Twenty Crops in the Wings

Peer-reviewed tracking of India's GMO regulatory system identifies more than twenty crops under various stages of research and field trial, including rice, wheat, maize, potato, sorghum, groundnut, cauliflower, okra, chickpea, pigeon pea, castor, and sugarcane, engineered for insect resistance, herbicide tolerance, drought and salinity tolerance, and nutritional enhancement. Cotton, brinjal, mustard, maize, and chickpea events have been reported as being in the final stages of field trials and "ready to be released commercially."

India's Genome-Editing Breakthrough

In May 2025, ICAR released DRR Dhan 100 (Kamala) and Pusa DST Rice 1 — India's first genomeedited crop varieties and, notably, the first genome-edited rice varieties released commercially anywhere in the world.

1. DRR Dhan 100 (Kamala)

Developed by ICAR-Indian Institute of Rice Research, Hyderabad, from the widely grown Samba Mahsuri background, Kamala uses SDN1 editing of the cytokinin oxidase (CKX2/Gn1a) gene to increase grain number per panicle. Field trial results reported a 19 percent yield increase, maturity roughly 7–20 days earlier than the parent variety, stronger culm strength resisting lodging, a 20 percent reduction in greenhouse-gas (methane) emissions attributable to the shorter cropping duration, and a projected saving of about 7,500 million cubic metres of irrigation water nationally if widely adopted.

2. Pusa DST Rice 1

Developed by ICAR-IARI, New Delhi, from the MTU 1010 background, this variety targets drought, salinity, and alkalinity tolerance, with reported yield gains ranging from roughly 9.7 percent up to 30.4 percent in saline and alkaline soils — directly relevant to eastern and coastal India's stress-prone rice tracts.

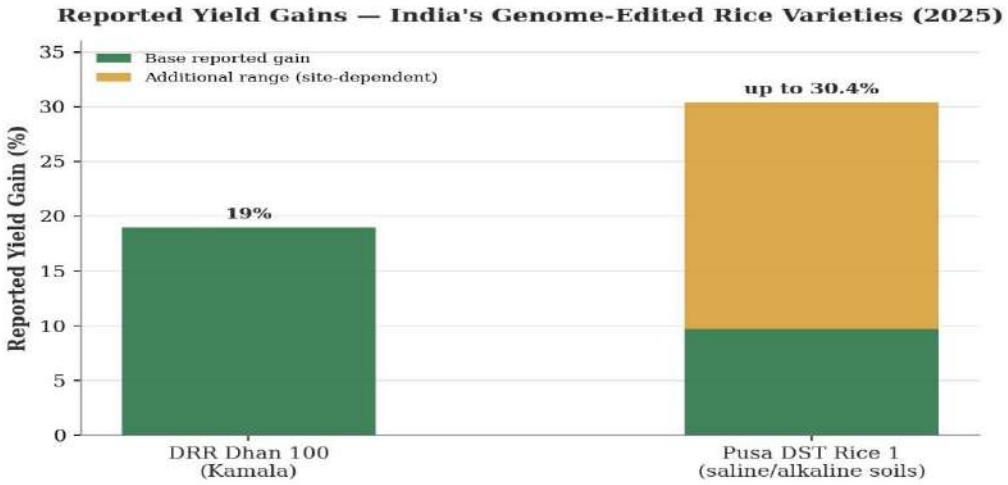


Figure 2.. Reported yield gains for India's two genome-edited rice varieties, 2025 field trial data.

Genomics-Based Herbicide-Resistant Crops

Genomics-based herbicide-resistant crops are developed by identifying and modifying the plant's own genes using genomics, marker-assisted breeding, or genome-editing tools such as CRISPR-Cas9, without necessarily introducing foreign DNA. Examples include CRISPR-edited rice resistant to imidazolinone herbicides, and genome-edited wheat and maize with modified ALS or EPSPS genes.

Role of Transgenic and Genomics in Canola (Low-Linolenic Acid)

Role of Transgenic Technology: Transgenic technology introduces or modifies genes involved in fatty acid biosynthesis. It can reduce linolenic acid content by suppressing genes such as FAD3, resulting in oil with improved oxidative stability and longer shelf life. It also enables the development of herbicideresistant canola (e.g., glyphosate- or glufosinate-resistant).

Role of Genomics: Genomics identifies genes controlling oil quality traits, including linolenic acid content. Marker-assisted selection (MAS) and genome editing (CRISPR-Cas9) are used to precisely modify genes like FAD3 without introducing foreign DNA, accelerating the development of canola varieties with low linolenic acid, high yield, and improved oil quality.

Why This Matters More Than The Agronomy

The scientifically interesting part is not the yield number but the timeline. ICAR initiated this genomeediting research in 2018 under the National Agricultural Science Fund; commercial release followed in 2025 — under seven years. Compare this to DMH-11, first developed in the early 2000s and still not in farmers' fields after roughly two decades, or Bt brinjal, approved at the regulatory level in 2010 and still under moratorium sixteen years later. ICAR's Director General has stated publicly that "many other geneedited crop varieties will be released in the coming years," signalling that genome editing, not transgenics, is now India's primary vehicle for translating laboratory research into field-ready varieties. Seed availability is still projected at roughly two years out as of the 2025 launch, pending IPR procedures — a reminder that even the faster track is not instantaneous.

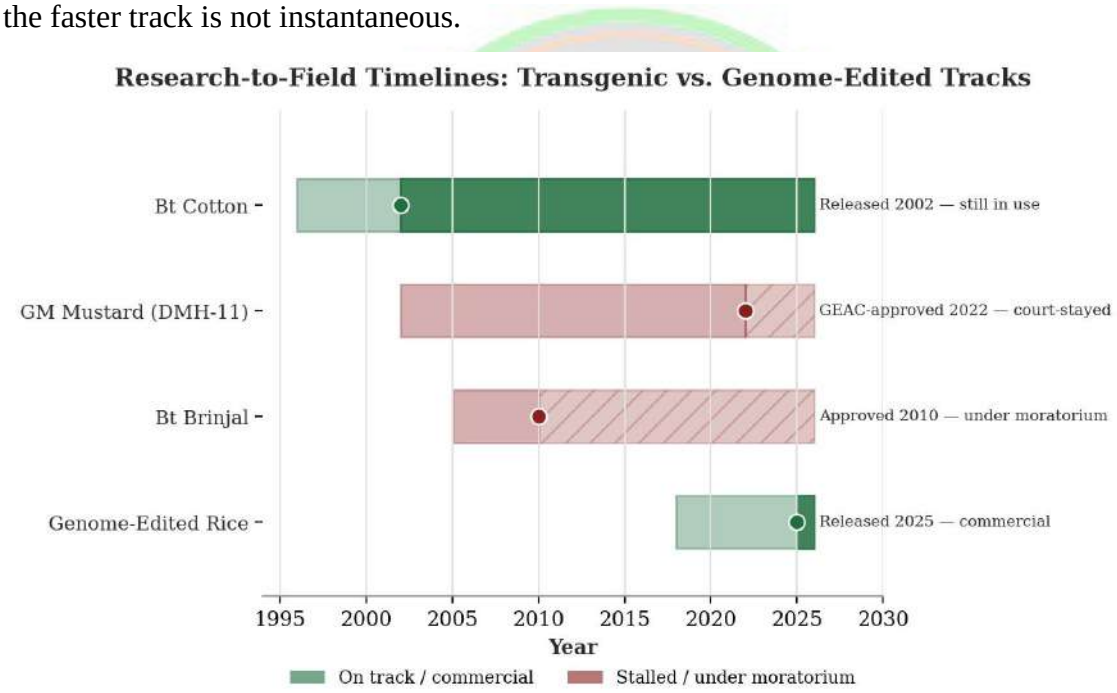


Figure 3. Research-to-field timelines compared: the transgenic track (Bt cotton, DMH-11, Bt brinjal) versus the genome-edited rice track.

The Global Landscape

Scale and Adoption

According to ISAAA Brief 57 (Global Status of Commercialised Biotech/GM Crops: 2024, released February 2026), 73 countries have adopted biotech crops in some form across the technology's 29-year commercial history, through a combination of cultivation and import. The United States, Brazil, Argentina, Canada, and India have historically accounted for the large

majority of global biotech hectarage, with adoption rates in major crops (soybean, maize, canola, cotton) at or near saturation — commonly cited in the 90–100 percent range in these five countries.

Africa: The Fastest-Moving Frontier

Africa is currently the most dynamic region for new biotech crop adoption. Ghana approved commercial cultivation of a pod-borer-resistant GM cowpea in 2024, developed domestically by CSIRSARI — a significant case because cowpea, unlike cotton, is a direct food and nutrition security crop for West Africa. Burkina Faso re-entered the list of Bt cotton-growing countries in 2024 after resolving fibrequality concerns that had caused a suspension between 2016 and 2023. Kenya lifted a decade-long ban on GM cultivation in 2022 and is advancing Bt maize, virus-resistant cassava, and late-blight-resistant potato through its regulatory pipeline, alongside ongoing court challenges.

The Contested Middle: Golden Rice and Bt Eggplant

The Philippines became the first country to approve commercial Golden Rice cultivation in 2021 and had earlier approved Bt eggplant (the same trait as India's Bt brinjal) in 2022. Both approvals were overturned by the Philippine Court of Appeals in April 2024 following a challenge from farmer and scientist groups, on grounds of inadequate risk-assessment procedure — a ruling explicitly noted by commentators as relevant to India's own pending mustard litigation. Bangladesh, meanwhile, commercialised Bt brinjal in 2013 without India's caution, but independent field research has since raised compliance and monitoring concerns, including failures to label the crop as genetically modified for farmers who purchased it. Golden Rice remains under regulatory consideration in Bangladesh as of the most recent reporting.

Advanced-Trait Pipeline Worldwide

Beyond insect and herbicide resistance, the global pipeline now includes drought-tolerant HB4 soybean and wheat (Argentina-origin technology, also approved in Brazil and the United States), nonbrowning apple and potato varieties, low-lignin alfalfa, high-oleic canola and safflower, and early-stage work in Latin America on GM rice, cassava, potato, and even coffee and pineapple. This diversification — beyond the traditional soybean-maize-cotton-canola quartet — mirrors India's own pipeline diversification into brinjal, mustard, chickpea, and rice.

COMPARATIVE SNAPSHOT: CROP-BY-CROP STATUS (2026)

Crop / Trait	Country	Technology	Status (2026)	Year
Cotton (Bollgard, insect resistance)	India	Transgenic	Commercial since 2002; ~94% adoption; only fully released GM crop	2002
Mustard (DMH-11, hybrid vigour)	India	Transgenic	GEAC-approved; commercial release stayed by Supreme Court	2022 / ongoing
Brinjal (Bt, insect resistance)	India	Transgenic	GEAC-approved 2009–10; under indefinite moratorium since 2010	2010
Brinjal (Bt eggplant)	Bangladesh	Transgenic	Commercialised 2013; compliance/monitoring concerns reported	2013
Brinjal (Bt eggplant)	Philippines	Transgenic	Approved 2022; biosafety permit revoked by court, 2024	2024 (revoked)
Golden Rice (vitamin A biofortification)	Philippines	Transgenic	First-ever approval 2021; permit revoked by court, 2024	2024 (revoked)
Rice (DRR Dhan 100 / Kamala, yield)	India	Genome-edited (SDN1)	Released commercially; world's first geneedited rice; seed ~2 yrs out	2025
Rice (Pusa DST Rice 1, stress tolerance)	India	Genome-edited (SDN1)	Released commercially alongside Kamala	2025
Cowpea (pod-borer resistance)	Ghana	Transgenic	Commercially approved; newest African adopter	2024

Cotton (Bt)	Burkina Faso	Transgenic	Re-approved after fibre-quality fix; suspended 2016–23	2024
Soybean / wheat (HB4, drought tolerance)	Argentina / Brazil / USA	Transgenic	Commercialised across multiple markets	2018–2019

Sources: GEAC/MoEFCC records; ICAR-IIRR and ICAR-IARI release documentation; ISAAA Biotech Update and Brief 57 (2024 data, released 2026); Philippine Court of Appeals rulings, 2024.

AN ORIGINAL FRAMEWORK: THE REGULATORY-READINESS GAP

The comparative table above exposes a pattern that a purely technology-by-technology summary would miss: scientific and agronomic readiness has almost no correlation with a crop's actual field status. Bt brinjal was declared safe by GEAC in 2010 and remains blocked sixteen years later; DMH-11 was declared safe for consumption and still cannot be sown; genome-edited rice went from a 2018 research programme to farmers' seed catalogues in seven years. This paper proposes a simple two-axis framework to make sense of this.

The Two Axes

- Technical Readiness (X-axis): whether multi-location field trials have established agronomic performance, safety, and stability — largely a scientific and time-bound variable.
- Classificatory Exposure (Y-axis): whether the crop's method of modification places it inside or outside the full GEAC/biosafety review track — a legal and definitional variable, not a scientific one.

Plotting India's cases on these two axes produces four quadrants:

High readiness, low exposure (genome-edited rice): fast commercialisation — the 2025 rice releases sit here.

- High readiness, high exposure (Bt brinjal, DMH-11): technically finished but politically and judicially frozen for over a decade — the defining Indian pattern for transgenic food crops.

- Low readiness, low exposure (early-stage gene-edited pulses, oilseeds): likely to be India's next wave of releases, since the classificatory hurdle is already removed.
- Low readiness, high exposure (many of the 20+ crop pipeline events): the slowest-moving category, compounding both scientific and regulatory delay.

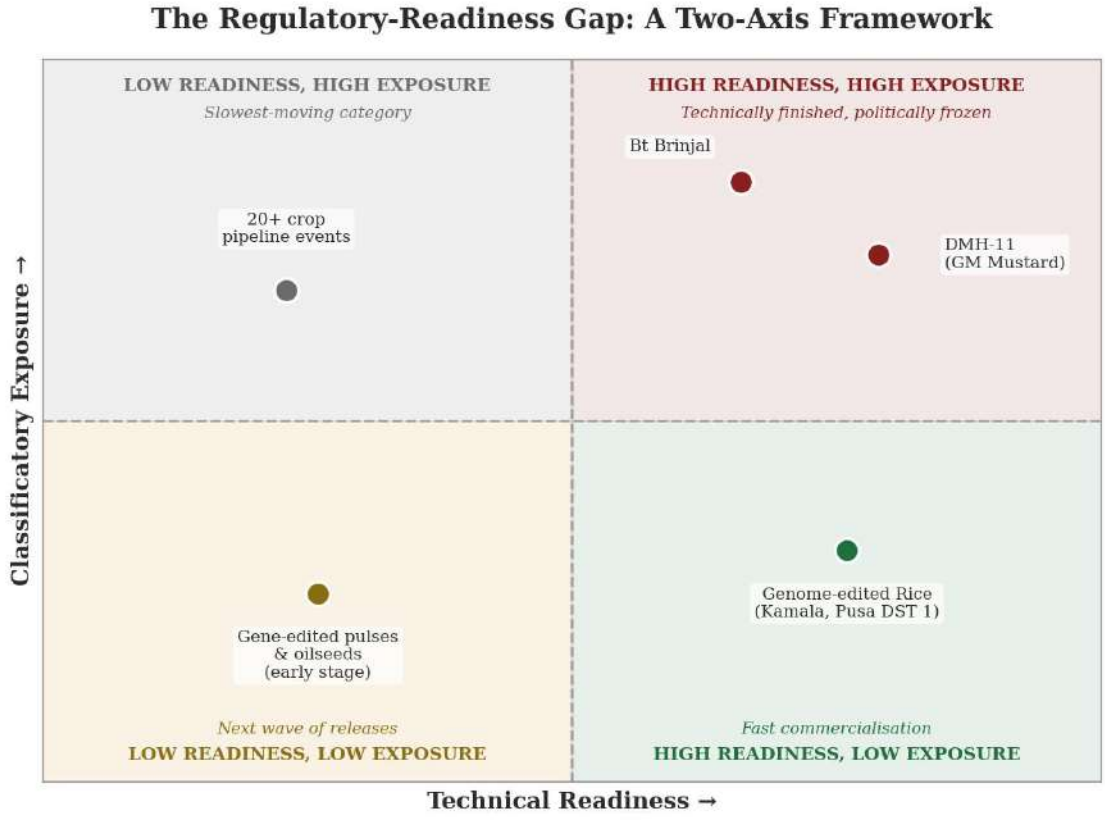


Figure 4. The Regulatory-Readiness Gap plotted across India's transgenic and genome-edited crop cases.

Socio-Economic And Environmental Considerations

Farm Income and Import Substitution

The Government of India has argued before the Supreme Court that GM mustard would lower edibleoil prices and reduce the country's heavy dependence on imported edible oil — a live economic argument given India imports a majority of its edible oil requirement. Genome-edited rice varieties are projected to lift yields by up to 20–30 percent while shortening the crop cycle by up to 20 days, which — if adopted at scale — would materially affect both farm income and national water-use accounting given rice's dominant share of irrigation demand.

Environmental Trade-offs

Reported environmental effects for the 2025 rice releases include a roughly 20 percent reduction in methane emissions (from shorter flooding duration) and an estimated 7,500 million cubic metres in irrigation-water savings nationally — figures directly relevant to India's climate commitments in agriculture. Bt cotton's environmental record after two decades is more mixed: it reduced insecticide use for bollworm control initially, but the more recent emergence of pink bollworm resistance illustrates that transgenic traits are not permanent solutions without refuge-crop management and trait rotation.

Farmer-Level Realities in Comparator Countries

Bangladesh's Bt brinjal experience is a cautionary comparator: independent field research reported that several of the seven original approval conditions — including consumer labelling — were not met in practice, with farmers reportedly unaware they were growing a genetically modified crop. This is a useful counterpoint to purely technical readiness arguments: successful lab and field-trial science does not guarantee successful farmer-level implementation without regulatory follow-through.

Legal, Ethical, And Public-Perception Challenges

The Judiciary as a De Facto Regulator

In both India and the Philippines, courts — not scientific committees — have become the final gatekeepers for transgenic food crop release. India's Supreme Court is adjudicating GM mustard's fate years after GEAC's own approval; the Philippine Court of Appeals directly revoked Golden Rice and Bt eggplant permits in 2024 on procedural risk-assessment grounds. This is a structural feature of transgenic food-crop governance in South and Southeast Asia that should be treated as a durable pattern, not a oneoff legal event.

Genome Editing's Regulatory Loophole Critique

Civil-society groups internationally have raised concerns that exempting SDN1/SDN2 genome editing from biosafety review may under-scrutinise off-target effects, even though the intended edit introduces no foreign DNA. India's regulatory position — treating SDN1/SDN2 as equivalent to conventional mutation breeding — is consistent with a broader global regulatory trend (also seen in the US, UK, and several Latin American jurisdictions) but remains contested by advocacy groups that argue biosafety assessment should be based on the novelty of the resulting trait rather than the technique used to create it.

Seed Sovereignty and Farmer Consent

Bangladesh's Bt brinjal labelling failure and the broader Golden Rice controversy both surface a recurring ethical question: whether farmers receiving genetically altered planting material understand what they are growing and retain meaningful choice. This question applies with equal force to genomeedited seed once it reaches Indian markets, since ICAR's own varieties are patent/IPR-protected pending release.

Conclusion

India in 2026 is running two genetic-technology tracks at two different speeds. Its transgenic track — Bt cotton, GM mustard, Bt brinjal — has produced exactly one commercial release in twenty-four years, with two further technically ready crops stalled in litigation and moratorium. Its genome-editing track, enabled by a single 2022 regulatory reclassification, produced the world's first commercial gene-edited rice varieties within seven years of the underlying research programme's start. The comparative and global evidence assembled here supports treating this gap — not any lingering scientific uncertainty — as the central obstacle to India's agricultural biotechnology adoption, and suggests genome editing, rather than further transgenic trait development, is where India's near-term productivity gains and possible export/technology leadership are most likely to materialise.

References

1. Drishti IAS, “Transgenic Crops” and “Genetically Modified Mustard,” Daily News Analysis, 2026.
2. PMC (National Center for Biotechnology Information), “Status of research, regulations and challenges for genetically modified crops in India,” GM Crops & Food.
3. Science.org (AAAS), “India nears approval of first GM food crop.”
4. C&EN Global Enterprise, “Mustard comes closer to becoming India's first genetically modified food crop.”
5. PSA (Office of the Principal Scientific Adviser, Government of India), “Breakthrough in the Indian Agriculture Industry in the form of Genetically Modified Mustard.”
6. ICAR, “Union Agriculture Minister Announces Two Genome-Edited Rice Varieties Developed in India,” May 2025.
7. ICAR-IIRR, official release communication on DRR Dhan 100 (Kamala) and Pusa DST Rice 1, May 2025.

8. Nature (nature.com/articles/d44151-025-00078-2), "India approves first genome-edited rice varieties."
9. ISAAA, Biotech Update: "ISAAA Global Report on Biotech Adoption Now Available" (Brief 57, 2024 data), March 2026.
10. ISAAA, "Countries Approving GM Crop Cultivation," Science Speaks blog, 2024.

Volume: 06 Issue No: 09

JEEVAMRUT: A NATURAL GROWTH BOOSTER FOR PLANTS

Article ID: AG-VO6-I09-127

Naresh Gupta

Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya , Gwalior (M.P.) India

Present address : Krishi Viyan Kendra, Manawar (Dhar-II) M.P., India

Abstract

Jeevamrut is a liquid organic manure that includes macro and micronutrients required by crops and is a rich source of natural carbon and biomass. Jeevamrut has shown to be more effective than other types of manures and may be utilized together with other manures. Such fertilizers are cheap, ecologically sound bio-inoculants with a high potential for increasing agricultural productivity in a sustainable manner. It can help to prevent the overuse of chemical fertilizers in the soil, which causes low soil fertility. Jeevamrut contains helpful bacteria that contribute to soil fertility. It transforms normal soil into rich, nutritious soil, allowing plants to develop quicker and generate more crop yields

Introduction

Jeevamrut is completely organic and has no negative impact on soil health. It consists of the terms "**Jeevan**" and "**Amrit**." The first word is Jeevan, which means "**Life**," and the second term is "**Amrit**", which means "Medicinal potion." Jeevamrut is an unique Indian bio-pesticide and organic manure produced through a unique fermentation procedure that combines cow dung, urine, jaggery, pulse flour, soil, and water. It is regarded as a great source of natural carbon, biomass, nitrogen, phosphorus, potassium, and other necessary micronutrients forcrops. Jeevamrut is not only inexpensive, but it is also helpful to plants and soil. It is especially advantageous for farmers who spend a lot of money on artificial fertilizers and pesticides. They may save money by using this incredible plant fertiliser. As a result, Jeevamrut is a better substitute to chemical fertilizer. Jeevamrut is entirely natural. As a result, it may be utilized in

organic farming, as a rich supply of microorganisms that fix nitrogen and solubilize phosphorus, and as a rich source of nutrients.

Ingredients required for the preparation of Jeevamrut

Take a barrel containing 200 L of water. Add water to 10 kg of local cow dung and 5-10 litres of cow urine (Goumutra). In a barrel, add 2 kg jaggery (Gud), 2 kg pulse flour, and add a small amount of farm soil. Then stir the solution well and left in the shade for 48 hours. Stir the mixture many times for at least 10 minutes. It begins to ferment. Jeevamrut is ready to use in 48 hours. It is suitable for use into 4 to 5 days.



Nutrient Composition of Jeevamrut

Jeevamrut is naturally acidic and an excellent source of macro (N - 1.97%, P - 0.172% and K - 0.29%,) and micronutrients (Mn - 47 ppm, and Cu - 50 ppm).

Application Method

Jeevamrut is available in two forms: solid and liquid. The solid form is commonly referred to as "Ghan jeevamrutam" it can be applied straight to the soil. You may apply it to the soil as a powder, similar to vermicompost or farm yard manure.

Liquid Jeevamrut's finished product may be given directly to the plant's root region in the soil. It might also be combined with water in a 1:10 ratio and sprayed over crops to be used for foliar application. The components of both forms, liquid and solid, are practically identical. In Liquid Form apply 5 to 10% Jeevamrut in water as a spray. 200 Litres of Jeevamrut are necessary for one acre of land. Spray every 7 to 14 days to have the best benefits.

Merits of Jeevamrut

Jeevamrut play a crucial role to increase the beneficial bacteria in soil. Acts as an agent to boost the microbial population and friendly bacteria in the soil; improves soil pH. Jeevamrut may be manufactured in 4-5 days, allowing it to be used successfully and often. It is suitable for all crops and boosts output. Jeevamrut lowers the expense of chemical fertilizers. It is simple to use as fertigation with irrigation water. Jeevamrut helps to promotes aeration, increases beneficial bacteria, is appropriate to all plants, and much more.

Limitations in use of Jeevamrut

Jeevamrut is made from animal remains and, as a result, has a highly unpleasant odour. Because it is liquid, it cannot be broadcast. The liquid has a shelf life of 10- 12 days after which it is no longer powerful.

Shelf-Life of Jeevamrut

Jeevamrut must be maintained in the shade and covered at all times. It must be ensured that no bug falls into the mixture or lays eggs in it. To avoid this, always keep the container covered with a wire mesh or plastic cover. It may be preserved for 60 to 75 days without losing quality as long as it is kept in the shade and stirred twice in a day. Because the solution thickens with time, additional water must be added as needed.

Conclusion

Jeevamrut is low-cost liquid organic manure that is abundant in natural carbon, helpful microorganisms like as nitrogen fixing and phosphate-solubilizing bacteria, and macro and micronutrients. Thus, the usage of Jeevamrut is the best organic substitute to chemical fertilizer and a superior bio enhancer that will enhance soil fertility and encourage sustainable crop production and quality. Jeevamrut contains a diverse microbiological life.

Volume: 06 Issue No: 09

BEYOND THE GUT: THE FISH MICROBIOME AND FISH HEALTH

Article ID: AG-VO6-I09-128

Testimona A[1] and Thangadurai K

ICAR-Central Institute of Fisheries Education, Mumbai -400061, India

*Corresponding Author: Testimona A

Introduction

Fish live in partnership with a huge variety of tiny living things that grow on their skin, gills and inside their gut. These tiny living things, which we call the fish microbiota include bacteria, fungi, archaea, viruses and many other small organisms that live with the fish. The fish microbiome means more than the community of microbes; it also covers their combined DNA, the chemicals they make and the complex ways they interact with the fish and the water around them. These microbial communities are not just passive. They help the fish break down food keep the system working, grow, develop and fight off harmful germs. Because of this they are very important for keeping fish healthy. Scientists first noticed the living things on fish almost a hundred years ago with studies on fish slime by Reed and Spence in 1929 and Gibbons in 1933. For many years the real importance of these microbes was not well understood. The use of culture-free DNA methods and next-generation sequencing has changed the game. It now lets scientists look at the variety, makeup and potential functions of fish communities with great detail. A key event in science was the launch of the Human Microbiome Project (HMP) by the National Institutes of Health (NIH) in 2007. Even though the HMP mainly studied humans it created ways to collect samples run sequencing tests analyze data and combine many kinds of measurements. Later scientists used these tools for fish and other animals. This progress moved fish microbiome research from finding which microbes were present, to understanding what they actually do and how they work with their host.

Fish gut microbiome and its importance in aquaculture

The rapid expansion of aquaculture has increased the need for sustainable strategies to improve fish health and productivity. Infectious and re-emerging diseases remain major constraints in finfish and shellfish farming worldwide. Although vaccines, antibiotics, and chemical therapeutics have played an important role in disease control, their excessive use has raised concerns about antimicrobial resistance, environmental contamination, and food safety. As a result, increasing attention is being given to environmentally friendly approaches that support the natural microbial communities associated with fish (El-Son et al., 2025). Among the different microbial habitats, the gastrointestinal tract is one of the most diverse and functionally important microbial ecosystems. A healthy gut microbiome supports digestion, nutrient absorption, metabolism, mucosal immunity, intestinal homeostasis, protection against pathogens, and also contributes to physiological adaptation, stress tolerance, behaviour, and overall host fitness. Therefore, maintaining a balanced and diverse gut microbiome is considered a promising strategy for improving fish health while reducing dependence on conventional antimicrobial agents(Tay et al., 2025).

Fish gut microbiome is not the same in every fish. Some bacteria show up across many important fish species. In fish like Rainbow trout, Nile tilapia, carps and Atlantic salmon the main bacterial families are Proteobacteria, Firmicutes and Fusobacteria. Other families such as Bacteroidetes, Actinobacteria and Verrucomicrobia change depending on the fish species and the environment. For instance, the bacterium Weissella is often found in Rainbow trout and the bacterium Cetobacterium is a part of the carp gut microbiome (Kanika et al. 2025). With these common bacterial groups the exact fish gut microbiome still varies between species and between different farming conditions. Learning about these fish gut microbiome communities is vital if we want to create microbiome-based methods that make fish healthier and help aquaculture grow in a way.

Even though some bacterial groups stay the same the fish gut microbiome shifts from one species to another and from one farming setup, to another. Knowing how the fish gut microbiome works is key if we want to build microbiome-based ways to keep fish healthy and to grow aquaculture that does not harm the environment.

Factors influencing the fish gut microbiome

The fish gut microbiome is a dynamic ecosystem influenced by both host-associated and environmental factors. Its composition varies with fish species, developmental stage, diet, nutritional status, starvation, environmental conditions, water quality, and exposure to antibiotics, disinfectants, and other chemicals. Intrinsic factors, including host genetics, age, reproductive status, immune competence, and physiological condition, influence the establishment of beneficial microbial communities. In contrast, extrinsic factors such as diet, water quality, temperature, and farming practices shape microbial diversity and stability. Together, these factors determine the structure and functional potential of the fish gut microbiome(Chen et al., 2022).

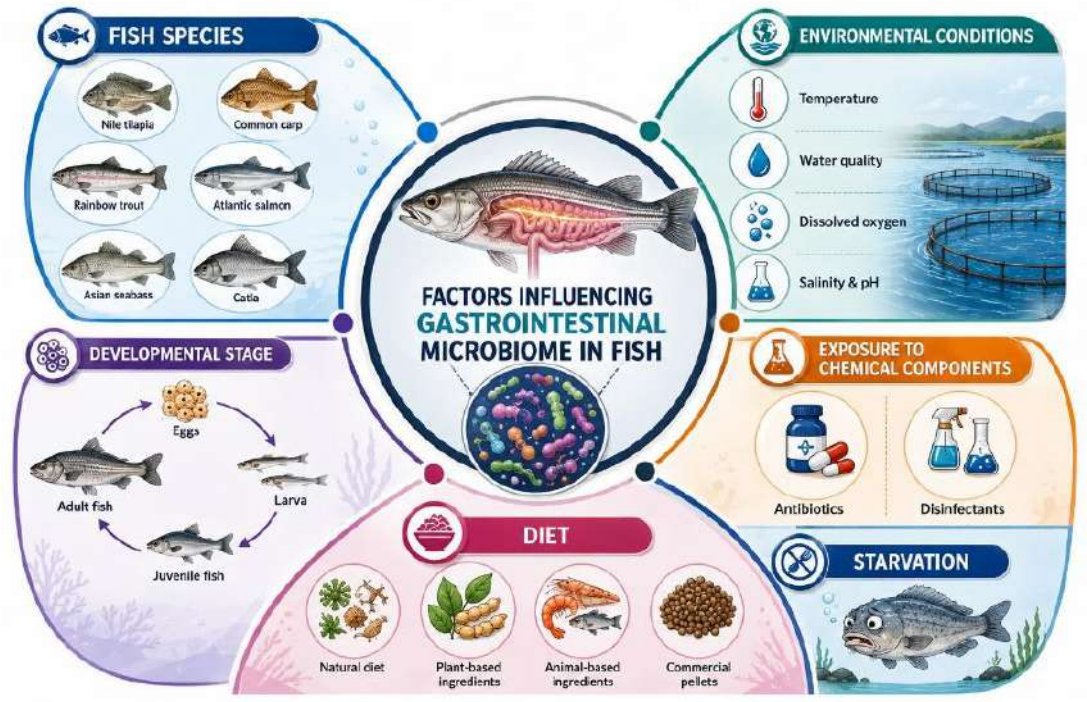


Fig 1. Major factors influencing the composition of the fish gastrointestinal microbiome

Dysbiosis: when the microbial balance is lost

A healthy fish gut microbiome maintains a delicate balance between beneficial and potentially harmful microorganisms, supporting digestion, immunity, metabolism, and overall health. When this balance is disrupted due to changes in microbial composition, metabolic activity, or distribution, a condition known as dysbiosis occurs. Dysbiosis is characterized by the expansion of opportunistic pathogens, loss of beneficial microbes, and reduced microbial

diversity. These changes impair normal gut functions, weaken host immunity, and increase susceptibility to disease. Increasing evidence suggests that dysbiosis is not merely associated with disease but actively contributes to its development and progression by disrupting normal microbial functions and host physiological processes.

Studies across several fish species have shown that bacterial, viral, and parasitic infections alter the normal gut microbial community, often leading to a decline in beneficial microorganisms and an increase in opportunistic pathogens. For example, infection with *Pseudomonas plecoglossicida* in yellow croaker caused progressive gut dysbiosis and increased mortality, whereas parasitic infection in zebrafish and viral and sea lice infections in Atlantic salmon was also associated with significant shifts in gut microbial composition (Li et al., 2020; Llewellyn et al., 2017). These findings suggest that monitoring changes in the gut microbiome could provide valuable insights into fish health and support the development of microbiome-based strategies for early disease detection and sustainable aquaculture.

Beneficial bacterial taxa as indicators of fish health

Comparisons of healthy and diseased fish, as in previous studies, have shown that disease is often associated with a decrease in beneficial bacteria and an increase in opportunistic pathogens. In particular, Fusobacteria, Firmicutes, and Cetobacterium have been proposed as indicators of a healthy gut microbiome, whereas their decline is frequently associated with dysbiosis and disease progression (Miyake et al., 2020). Evidence from several fish species further supports this concept. For example, Asian seabass affected by tenacibaculosis exhibit a decrease in Fusobacteria and Firmicutes, accompanied by an increase in Proteobacteria. Likewise, disease-associated shifts in microbial composition have been reported in Atlantic salmon, rainbow trout, common carp, grass carp, yellow croaker, groupers, and other cultured fishes, demonstrating that alterations in gut microbial communities are closely associated with disease status (Mougin and Joyce, 2022). Although no single microbial taxon can be considered a universal biomarker for all fish diseases, identifying disease-specific microbial signatures offers considerable promise for the early diagnosis of disease, health monitoring, and the development of microbiome-based disease management strategies in aquaculture.

Opportunistic bacteria as biomarkers of disease

While loss of beneficial microbes can lead to disease in fish, an increase in pathogenic, opportunistic microbes often plays a more important role in the development of fish diseases.

One of the first indicators of an unhealthy gut is an increase in Proteobacteria. Some bacterial groups have been identified as microbial "warning signals" for disease, according to researchers. For example, *plesiomonas* has been linked to viral infections in gibel carp, whereas changes in *plesiomonas* and *lawsonia* have been associated with tapeworm infections in common carp. The scientists found that in zebrafish with intestinal parasites, the levels of *plesiomonas* went down and the levels of pseudomonas went up, showing that the normal gut microbiome was disrupted. Similar changes have also been seen after antibiotic treatment, which suggests these bacteria may be good indicators of gut imbalance, rather than markers of one specific disease. These microbial alterations suggest that gut bacteria may serve as early biomarkers for monitoring fish health and early detection and treatment of disease.

Functional alterations in the gut microbiome associated with disease

Changes in the types of bacteria in the gut do not always lead to changes in the functions those bacteria perform because different microbial communities can carry out similar biological roles a phenomenon called functional redundancy. Therefore, changes in the functions of the gut microbiome may offer reliable signs of disease than changes in the composition of bacteria alone. Recent progress in sequencing technologies and bioinformatic tools such as PICRUSt allows researchers to predict metabolic pathways from 16S rRNA sequencing data and to assess changes linked to disease. Studies have shown that infections can alter pathways that involve motility, secretion systems, energy metabolism, amino acid metabolism carbohydrate metabolism, transport and interactions between host and microbes. For instance, crucian carp affected by red-operculum disease displayed increased motility, secretion systems and toxin-related pathways. In rohu (*Labeo rohita*) infected with *Argulus siamensis*, pathways related to energy metabolism and transport were enriched, while pathways for signal transduction and cell growth were reduced. Likewise grass carp with enteritis showed changes in amino acid, carbohydrate and xenobiotic metabolism whereas diseased Yunlong grouper showed enrichment of pathways related to carbohydrate metabolism, transport, and secondary metabolite biosynthesis (Mondal et al. 2022; Tran et al. 2018; Ma et al., 2019). Although functional profiling remains a developing field in fish microbiome research these results suggest that functional signatures, including altered metabolic pathways, genes and metabolites could act as biomarkers, for disease diagnosis and health monitoring. However more research is required before these functional biomarkers can be used routinely in aquaculture.

Microbiome as an early warning system for fish disease

The fish microbiome is made up of microbial communities that live on the skin, gills and in the gastrointestinal tract. Among these the gut microbiota receives the attention because it plays a key role in nutrition, metabolism, immune regulation and overall host health. Continuous interactions between the fish and its associated microorganisms help keep the fish healthy whereas a break in these interactions can raise the risk of disease.

Growing evidence shows that the composition and function of the microbiome are affected not by pathogens but also by host traits and environmental factors such as water quality, temperature, diet, stocking density, antibiotic exposure and farming practices. Because of this dysbiosis often appears before any clinical signs. By combining information on composition, diversity, functional changes, host factors and environmental conditions we can gain a fuller understanding of disease progression spot microbiome disturbances early and support timely disease management and targeted interventions, in aquaculture.

Microbiome-based approaches for fish health monitoring

Recent advances in fish microbiome research are opening possibilities for monitoring fish health before visible signs of disease appear. Of relying only on conventional diagnostic methods scientists are exploring changes in microbial communities as early indicators of disease. Since studying the gut microbiome usually requires collecting samples, which is invasive and often requires sacrificing the fish researchers are investigating non-invasive alternatives such as faecal, skin mucus and pond water samples. Faecal samples provide information about the gut microbiota but may not fully represent the intestinal microbial community and can be influenced by contamination from pond water.

The skin and gills which act as the first line of defence also harbour diverse microbial communities and changes in this mucosal microbiota may reflect the health status of the fish. Recent studies suggest that mucus sampling is a stress-free alternative for health assessment. Researchers are also exploring the microbiota of pond water as a monitoring tool although water samples alone cannot fully represent the gut microbial community because its similarity with environmental microbiota varies throughout the culture period. At the time the rapid development of next-generation sequencing (NGS) has greatly improved our understanding of fish-associated microbial communities and enabled comprehensive analysis of microbiota in several aquaculture species, including zebrafish, grass carp, Asian seabass, Atlantic salmon and

olive flounder. Although microbiome-based monitoring is still evolving, combining sampling with advanced sequencing technologies holds great promise, for early disease detection improved health monitoring and sustainable aquaculture management.

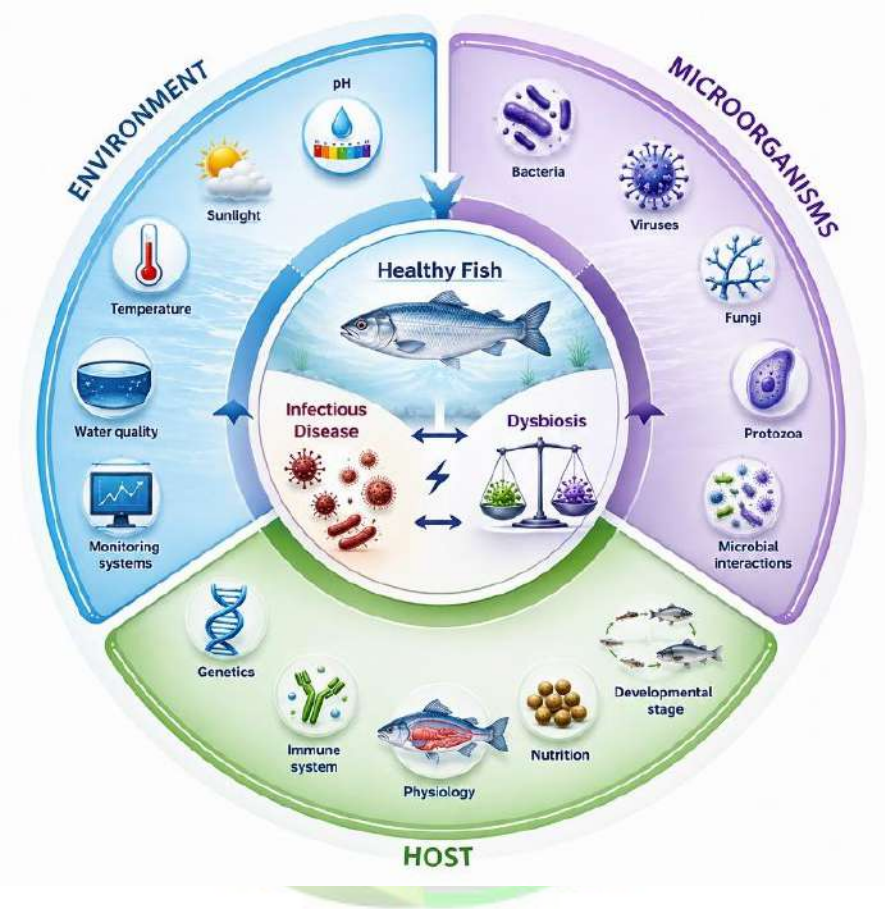


Fig 2. A schematic illustration of the host-microbiome-environment interactions influencing fish health

Conclusion

The fish microbiome plays a vital role in maintaining health by supporting nutrition, immunity, and disease resistance. Its composition is continuously influenced by host factors, environmental conditions, and farming practices. Disturbances in this delicate balance can lead to dysbiosis, increasing the risk of disease. Growing evidence suggests that changes in the microbiome often occur before clinical signs become visible, making microbial signatures promising early indicators of fish health. Advances in next-generation sequencing and non-invasive sampling methods are further improving our ability to monitor these microbial changes.

Although microbiome-based diagnostics are still evolving, they hold great promise for the development of early disease detection systems and targeted health management strategies, including probiotics, prebiotics, synbiotics, phage therapy, and postbiotics. Harnessing the fish microbiome will contribute to healthier stocks, reduced disease outbreaks, and more sustainable aquaculture.

References

Chen, C.Z., Li, P., Liu, L. and Li, Z.H., 2022. Exploring the interactions between the gut microbiome and the shifting surrounding aquatic environment in fisheries and aquaculture: A review. *Environmental Research*, *214*, p.114202.

El-Son MAM, Elbahnaswy S, Khormi MA, Aborasain AM, Abdelhaffez HH, Zahran E. Harnessing the fish gut microbiome and immune system to enhance disease resistance in aquaculture. Fish Shellfish Immunol. 2025 Aug;163:110394. doi: 10.1016/j.fsi.2025.110394. Epub 2025 May 9. PMID: 40350102.

Kanika NH, Liaqat N, Chen H, Ke J, Lu G, Wang J and Wang C (2025) Fish gut microbiome and its application in aquaculture and biological conservation. Front. Microbiol. 15:1521048. doi: 10.3389/fmicb.2024.1521048

Li, C.H., Xiong, J.B., Ding, F.F. and Chen, J., 2020. Immune and gut bacterial successions of large yellow croaker (Larimichthys crocea) during Pseudomonas plecoglossicida infection. Fish & Shellfish Immunology, 99, pp.176–183.

Li, T., Li, H., Gatesoupe, F.J., She, R., Lin, Q., Yan, X., Li, J. and Li, X., 2017. Bacterial signatures of "Red-Operculum" disease in the gut of crucian carp (Carassius auratus). Microbial Ecology, 74, pp.510–521.

Llewellyn, M.S., Boutin, S., Hoseinifar, S.H. and Derome, N., 2014. Teleost microbiomes: the state of the art in their characterization, manipulation and importance in aquaculture and fisheries. Frontiers in Microbiology, 5, p.207.

Ma, C., Chen, C., Jia, L., He, X. and Zhang, B., 2019. Comparison of the intestinal microbiota composition and function in healthy and diseased Yunlong Grouper. AMB Express, 9(1), pp.1–11.

Miyake, S., Soh, M., Azman, M.N., Ngoh, S.Y., Orbán, L. and Seedorf, H., 2020. Insights into the microbiome of farmed Asian sea bass (Lates calcarifer) with symptoms of [reference incomplete in the list you provided].

Mondal, H.K., Maji, U.J., Mohanty, S., Sahoo, P.K. and Maiti, N.K., 2022. Alteration of gut microbiota composition and function of Indian major carp, rohu (Labeo rohita) infected with Argulus siamensis. Microbial Pathogenesis, 164, p.105420.

Mougin, J. and Joyce, A., 2023. Fish disease prevention via microbial dysbiosis-associated biomarkers in aquaculture. Reviews in Aquaculture, 15(2), pp.579–594. (Your article currently cites this as 2022.)

Tran, N.T., Zhang, J., Xiong, F., Wang, G.T., Li, W.X. and Wu, S.G., 2018. Altered gut microbiota associated with intestinal disease in grass carp (Ctenopharyngodon idellus). World Journal of Microbiology and Biotechnology, 34, pp.1–9.

Yoon, D.S., Kim, J.H., Kim, I.C., Wang, Y., Yang, Z., Lee, M.C. and Lee, J.S., 2025. Effects of environmental factors on host-microbiota interactions in the guts of aquatic organisms: A review. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology*, p.110381.

Volume: 06 Issue No: 09

SUCCESS STORIES AND IMPACTS OF COASTAL CAGE FARMING IN NORTH KERALA: CASE STUDIES FROM KOZHIKODE, KANNUR, AND KASARAGOD

Article ID: AG-VO6-I09-129

Shilta M.T., Imelda Joseph, Madhu K., Vinod K., Asokan P.K., Ramya Abhijith, Suresh Babu P.P., Saju George, Anoop K. G., Anirudh K., Suresh V. V. R

ICAR–Central Marine Fisheries Research Institute, Calicut Regional Station, West Hill P.O., Kozhikode - 673 005, Kerala, India

*Corresponding Author : Shilta M.T

Abstract

Cage fish farming in the coastal waters of Northern Kerala, facilitated by ICAR-CMFRI, Calicut Regional Station, has emerged as a vital livelihood option, particularly for marginalised communities. This paper compiles case studies from Kozhikode, Kannur, and Kasaragod that illustrate the socio-economic transformation achievable through cage aquaculture. It features an inspiring individual success story from Mujukunnu, Kozhikode, and highlights community-based initiatives involving the Mavilan tribes of Kasaragod and scheduled caste beneficiaries of Kannur. In addition to documenting these impacts, the study examines prevailing constraints, proposes strategies for scaling up the model, and discusses the broader socio-economic implications of promoting sustainable cage farming in the region.

Keywords: Cage aquaculture, Livelihood improvement, Tribal empowerment, North Kerala, On-site marketing

Introduction

Kerala's backwater ecosystem offers an ideal setting for sustainable coastal aquaculture, where cage fish farming has emerged as a promising livelihood option for small-scale fishers, marginal farmers, and tribal communities. Since 2015, the Calicut Regional Station of ICAR-CMFRI has spearheaded initiatives to promote cage aquaculture in North Kerala through capacity building, site-specific technology dissemination, and the establishment of successful

demonstration units. These efforts have been directed not only toward enhancing fish production but also toward strengthening the socio-economic resilience of coastal and tribal populations.

Materials and Methods

The initiative primarily targeted individuals and marginalized communities residing along the backwaters of Korapuzha (Kozhikode), Kavvayi (Kannur), and Bekal River (Kasaragod). Potential sites were selected based on a minimum water depth of 3 m, favorable environmental parameters, and the absence of industrial or domestic waste discharge. Field demonstrations on cage fabrication and installation were carried out at Atholi and Mujukunnu (Kozhikode), Payyanur and Kuppam (Kannur), and Bekal (Kasaragod). The most commonly promoted cage dimension was 4×4×3 m (48 m^3), constructed with galvanized iron (GI) frames and inner/outer netlon nets. Depending on site characteristics and farmer requirements, cage sizes varied between 4×4×3 m and 6×4×3 m. Technical and financial support was provided during the initial year, with continued technical guidance offered throughout subsequent production cycles. Each initiative encompassed site selection, cage fabrication, seed stocking, feed management, and routine monitoring. ICAR–CMFRI contributed through targeted technical interventions, including training programmes, on-site demonstrations, and economic performance evaluations (Figure 1 & 2).



Fig. 1 On-field demonstration on cage fabrication



Fig. 2. Demonstration on preparation of floatation system

Technology Dissemination

· **Cage Design:** Galvanized iron (GI) pipe cages with dimensions of 3×3×3 m (27 m^3) or 4×4×3 m (48 m^3).

· **Species Stocked:** Asian seabass (*Lates calcarifer*), pearl spot (*Etroplus suratensis*), and red snapper (*Lutjanus argentimaculatus*).

· **Feeding Protocol:** Fish were initially fed with commercial pellet feed at 12–15% of body weight, gradually reduced to 3–5%. For carnivorous species, feeding was later supplemented with low-value fish.

· **Data Collection:** Monthly monitoring of growth and survival was undertaken. Economic performance was assessed through Net Present Value (NPV), Benefit–Cost Ratio (BCR), and Internal Rate of Return (IRR), calculated over a five-year project cycle at a 15% discount rate (Aswathy, 2020).

Case Study 1 – Success story of Mr. Sathyan, Mujukunnu, Kozhikode

Mr. Sathyan, a mason and part-time fisherman, initially faced failure in 2016 due to cannibalism in PVC cages. Under ICAR–CMFRI's participatory programme in 2017, he received training and GI cages, initiating sustainable cage culture.

Key Milestones

- **2018:** Stocked 250 pearl spot in an 18 m^3 cage; achieved 95% survival, harvested 50 kg, and generated ₹27,500 (Fig.3).
- **2019:** Capture-based aquaculture of pearl spot and red snapper yielded 90 kg and ₹51,500 revenue.
- **2020:** Stocked 600 seabass and 500 pearl spot in a 48 m^3 cage; despite COVID-19 disruptions, harvested 225 kg and earned ₹1,53,500 (Fig. 4).



Fig. 3. Stocking of pearlspot seeds in cage



Fig. 4. Harvest of seabass from cage

By 2022, he expanded from two cages to 36 cages (seabass, pearl spot, red snapper, Chitralada tilapia) (Fig. 5), supported by CMFRI and the State Fisheries Department. In 2021 alone, he earned ₹8,00,000 from eight seabass cages.



Fig. 5. Cage Farm at Mujukunnu, Kozhikode

Economic Indicators (3×3×3 m cage, 8 months)

- **Seabass:** 300–350 kg; BCR 1.92; IRR 99.5%.
- **Red snapper:** 250–300 kg; BCR 1.74; IRR 93.2%.
- **Chitralada tilapia:** 400–450 kg; BCR 2.36; IRR 70.9%.

This case demonstrates how technical guidance, proper planning, and market integration can transform rural livelihoods. Sathyan's success encouraged 37 new farmers in Moodady Panchayat to adopt cage farming, demonstrating the potential of this model for wider community empowerment.

Case Study 2 – Empowering the Mavilan Tribes of Kasaragod, Kerala:

The Mavilan tribe, inhabiting the hilly and forested regions of northern Kasaragod, has traditionally depended on agriculture and forest-based livelihoods. In 2019, under the Tribal Sub-Plan (TSP) programme, the Calicut Regional Station of ICAR–CMFRI launched a cage farming initiative for 22 Mavilan beneficiaries from the Kurichikunnu colony of Pararam Grama Panchayat, Bekal, Kasaragod (Fig. 6).



Fig. 6. Mavilan tribal beneficiaries, Bekal, Kasaragod

Formation of Self-Help Groups (SHGs)

Three SHGs were formed to promote collective aquaculture initiatives within the Mavilan tribal community:

- **Navodaya SHG** – 10 members (6 males, 4 females)
- **Sangamithra SHG** – 7 members (5 males, 2 females)
- **Udhayam SHG** – 5 members (3 males, 2 females)

The Self-Help Groups (SHGs) were formed to strengthen community participation in aquaculture and to promote equitable involvement of both men and women. Prior to this initiative, most members were engaged in labour-intensive occupations such as painting and masonry, while many women worked under the Thozhilurappu (MGNREGA) scheme. None of them had prior experience in aquaculture. To build their capacity, the SHGs were provided with technical guidance, farm inputs, and on-site demonstrations, enabling them to effectively undertake cage culture operations.

Skill Development & Capacity Building

To promote sustainable livelihood diversification, targeted skill development programmes were organized, focusing on aquaculture techniques, water management, and essential business skills. As part of this effort, the Calicut Regional Station of ICAR-CMFRI conducted a comprehensive "Hands-on Training and On-field Demonstration Programme on Cage Culture of Marine Fishes," which included:

- **Theoretical Modules** – Sessions on site and species selection, feed and disease management, stocking practices, and integrated multi-trophic aquaculture techniques (Fig.7).



Fig.7. Trainning on cage culture practices to Mavilan tribes of Bekal, Kasargod, Kerala

- **Practical Modules** – On-field demonstrations on cage fabrication (Fig. 8), installation and maintenance, fish seed acclimatization and stocking etc.



Fig. 8. Attachment of floats to cage

- **Field Exposure**: A visit to a local cage farming site in Payyanur, Kannur, was organised for selected beneficiaries to gain more knowledge on cage farming culture practices. The combination of hands-on training, demonstrations, and exposure visits helped enhance the technical capacity of the beneficiaries, preparing them for sustainable cage aquaculture practices.

  These initiatives enabled participants to gain practical and theoretical knowledge on:

- Selecting suitable sites for cage culture.
- Identifying appropriate fish species and acclimatizing them for farming.
- Setting up and managing cages, including feeding and disease control.

Technology Implementation

Site Selection

The Bekal River (12º24'23.76"N, 75º1'58.908"E) near the Kurichikunnu tribal colony was identified as an ideal location for cage farming, meeting criteria like suitable water depth (3 meters) and clean water, free from industrial or domestic waste (Fig. 9).

Technology Dissemination

The program introduced grow-out culture of marine finfishes in galvanized iron (GI) cages. Five units of 4x4x3m cages were fabricated and installed, along with an 8-meter-long catwalk for easy access.



Fig. 9. GI cages installed at Bekal, Kasargod



Fig. 10. Stocking of seabass fingerlings in GI cages

Inputs Provided

- **Seeds:** Fingerlings of Asian seabass (*Lates calcarifer*) and pearl spot (*Etroplus suratensis*).
- **Feed:** High-quality floating pellet feed.
- **Infrastructure:** Cages, GI catwalk, nets, hapa, floats, and anchors
- **Equipments:** Freezer, weighing balance

Grow out culture of marine finfishes in cages: Grow-out culture of marine fishes, including Asian seabass (*L. calcarifer*, locally known as Kalanji) and Pearl-spot (*E. suratensis*, locally known as Karimeen), was conducted in GI cages. Initially, five cages (4x4x3m, 48 m^3) were used, with Asian seabass fingerlings (8-10 cm; 600 individuals) stocked in three cages and Pearlspot fingerlings (3-4 cm; 2000 individuals) in two (Fig. 10). The fingerlings were transported from Kumta, Karnataka, in insulated trucks (Fig. 11).



Fig. 11. Transportation of seabass fingerlings in insulated truck

Fishes were fed with Nutrilla floating pellet feed (45% protein and 10% crude fat). Feeding began at 12% of body weight and was gradually reduced to 3% as the culture progressed. For seabass, low-value fish was also provided alongside the pellet feed. After 8–9 months, seabass reached an average weight of 1–1.5 kg per fish (Fig. 12), while pearl spot attained 200–250 g (Fig. 13). A 48 m^3 cage stocked with 600 seabass yielded a gross revenue of Rs. 1.8 lakhs and a net profit of Rs. 86,200, with an internal rate of return (IRR) of 88.5% and a benefit–cost ratio (BCR) of 2.29. Similarly, a 48 m^3 cage stocked with 2,000 pearl spot generated Rs. 1.75 lakhs in gross revenue and Rs. 55,900 in net profit, with an IRR of 86.9% and a BCR of 4.25. Pearl spot commanded a high market price (Rs. 500–600/kg locally). The initiative proved economically

rewarding, particularly through partial harvests, providing substantial livelihood support to the Mavilan tribal community.



Fig. 12. Harvest of seabass



Fig. 13. Harvest of pearlspot

Harvest *Mela*: A harvest mela for seabass (Fig. 14) and Pearlspot (Fig. 15) was organized, during which ICAR-CMFRI actively supported the Mavilan tribal community by empowering them to market their produce through social media platforms, local restaurants, and wholesale distributors.

Empowering the Mavilan tribal community in aquaculture required addressing a range of socio-economic, environmental, and technical challenges.



Fig. 14. Harvest Mela of seabass



Fig. 15. Harvest Mela of pearlspot

Challenges Addressed

1. **Technical Knowledge Gap**: Training was provided to bridge the gap in aquaculture skills.

2. **Financial Barriers**: The initiative provided financial support in a phased manner, starting with 100% coverage in the initial years and gradually reducing assistance to encourage self-reliance.
3. **Cultural and Traditional Hesitancy**: Awareness programmes and consistent engagement helped address resistance to adopting new practices.
4. **Infrastructure Limitations**: Support included supply of cages, nets, seeds, feed, and storage equipment.
5. **Market Access**: Assistance was provided to connect the Mavilans with wholesalers, restaurants, and local markets, ensuring fair prices for their produce.

Social and Economic Transformations

The project significantly improved the living standards of the participating tribal families in

- Construction of new houses.
- Renovation of existing houses.
- Purchase of household items like refrigerators, televisions, and mobile phones.
- Investment in children's education and debt clearance.

During the first four years of fish farming, beneficiaries received comprehensive support from ICAR-CMFRI, including both technical guidance and financial assistance. In subsequent farming seasons, this support transitioned to technical guidance alone. The Mavilan tribes gradually transitioned to self-reliant cage farmers, with some families adding more cage units independently. The successful demonstration of high-value marine finfish culture in low-cost estuarine cages significantly improved livelihoods and empowered the Mavilan tribes of Kasaragod to sustain cage culture independently without financial aid.

Case Study 3-Empowering Scheduled Caste Communities through Cage Farming Initiatives

Under the Scheduled Caste Sub-Plan (SCSP) programme, a total of twenty beneficiaries (formed a self-help group named *KuppamFish*, A*quaFish*, *Spotfish and Nanma)* from two Scheduled Caste communities—Valluvan and Pulayan—were identified during 2020–2021 for livelihood development through cage fish farming. They were residing in Pariyaram Grama Panchayat, and Payyanur Municipality of Kannur district.





Fig. 16. Training on cage farming at Kannur, Kerala **Fig. 17. Demonstration on cage farming practices to SC beneficiaries of Kannur**





Fig. 18. Stocking of seabass in cages **Fig. 19. Harvest of seabass in cages**

Training (Fig. 16) and demonstration programmes (Fig. 17) on marine finfish grow-out cage culture was organized for these selected beneficiaries. Subsequently, four GI cage units (4 × 4 m dimension) were installed and stocked with seabass and pearl spot fingerlings (Fig. 18). The project provided complete technical and financial support, including nutritionally balanced floating pellet feed (45% protein, 10% crude fat), administered four times daily. After a eight-month culture period, the seabass attained an average weight of 850–1100 g (Fig.19). The successful demonstration of high-value marine finfish culture in low-cost estuarine cages showcased a viable livelihood model and encouraged broader participation from the Scheduled Caste communities in the region.

Farmer-led Technological Innovations in North Kerala

Progressive farmers have adopted the following innovations to boost productivity and sustainability:

- **Surveillance units** for remote cage monitoring
- **On-field watch sheds** for feed storage and management (Fig.20)
- **On-site marketing** via partial harvests and social media promotions
- **Enterprise development**



Fig.20. On-field watch sheds



Fig.21. Enterprise developed by Progressive farmer of Kannur

Enterprise development by Progressive farmer

Mr. Sudhish P., a progressive cage fish farmer from Payyanur, Kannur, began cage farming in 2018 under the ICAR-CMFRI–NFDB scheme. Previously an electrician, he transitioned to full-time cage and mussel farming with his family. Starting with two GI cages provided by ICAR-CMFRI during 2018–2019, he later added six more cages, now managing a total of eight units cultivating seabass, pearlspot, and red snapper. As a pioneer of cage farming in Payyanur, he has inspired many others to adopt the practice. In 2021, he established an enterprise, "SS Distributors – Fish Feed and Fish Farming Material," which supplies essential inputs to farmers across Kannur district (Fig.21).

Constraints Faced by Cage Farmers

Despite the success, several challenges were noted:

- High seed cost
- Lack of hatcheries in North Kerala

- No insurance facilities
- Natural calamities (flooding, water quality shifts)
- Wildlife predation (otters)
- Conflicts with tourism
- Inadequate credit and financial access

Recommendations

To enhance adoption and scalability:

- Establishment of regional finfish hatcheries for consistent seed supply
- Dedicated financial support schemes for new entrants
- Inclusion of cage aquaculture under government insurance and credit programs
- Better stakeholder coordination (tourism-fisheries convergence)

Conclusion

Coastal cage farming in North Kerala, facilitated by ICAR-CMFRI Calicut RS, has transformed livelihoods, particularly among economically and socially marginalized communities. The models implemented in Mujukunnu, Payyanur, and Kasaragod demonstrate the potential of community-based aquaculture, particularly when backed by scientific inputs, innovation, and participatory engagement. With proper policy and infrastructural support, cage aquaculture can emerge as a robust contributor to Kerala's blue economy. With vast unutilized estuarine resources and growing demand for high-value fish, North Kerala holds significant potential for large-scale cage farming. However, insurance coverage, seed availability, and policy support remain critical for sustained growth.

Acknowledgements

The authors thank the Director, ICAR-CMFRI, Head, Mariculture Division and SIC, Calicut Regional Station, Project investigators of NFDB, TSP/SCSP for continuous support. Funding agencies were ICAR and NFDB. Special thanks to local panchayats, TSP/SCSP beneficiaries, and progressive farmers who contributed to the success of the project.

Volume: 06 Issue No: 09

BIOCHAR: A SUSTAINABLE SOIL AMENDMENT FOR CLIMATE-RESILIENT AGRICULTURE

Article ID: AG-VO6-I09-130

Bommayasamy, N* and Selva Rani, A.

*ICAR-Central Coastal Agricultural Research Institute, Ella, Old Goa, Goa-403402, India

Assistant Professor, Agricultural Research Station, Kovilpatti, Thoothukudi, Tamil Nadu

*Corresponding Author: Bommayasamy, N.

Abstract

Climate change, declining soil fertility, water shortages, nutrient depletion, and rising environmental pollution pose major obstacles to sustainable agricultural production. Biochar, a carbon-dense substance generated through the pyrolysis of biomass in oxygen-restricted environments, has surfaced as a viable soil amendment to tackle these limitations. Its permeable composition, extensive specific surface area, surface functional groups, and cation-exchange capacity allow biochar to enhance the physical, chemical, and biological characteristics of soil. Biochar can improve soil structure, porosity, moisture retention, and nutrient retention, while also creating advantageous environments for beneficial microbes. It also improves nutrient use efficiency, alleviates moisture stress, promotes carbon sequestration, reduces greenhouse gas emissions, and facilitates contaminant immobilisation. Moreover, biochar can function as a medium for the controlled release of agrochemicals and as an adsorbent for environmental contaminants. However, its efficacy varies with feedstock, pyrolysis parameters, application frequency, soil classification, crop variety, and climatic factors. Hence, suitable characterisation and localised application are crucial for actualising its potential in climate-resilient agriculture.

Introduction

Agriculture is increasingly vulnerable to climate fluctuations, aridity, soil deterioration, diminishing soil organic carbon, nutrient depletion, and ecological contamination. These pressures negatively impact soil functions, the availability of water and nutrients, crop yield, and the enduring viability of agricultural systems. At the same time, traditional practices of managing

crop residues through incineration increase greenhouse gas emissions and air pollution. Biochar is a carbon-rich material produced by heating biomass such as crop residues, wood, and other organic wastes under oxygen-limited conditions through a process known as pyrolysis. Slow pyrolysis is the preferred method for biochar production because it yields more biochar than bioenergy. Biochar possesses a highly porous structure and a large specific surface area, particularly when produced at higher temperatures (600–750°C), which enhances its ability to retain water and nutrients.

Biochar offers an opportunity to transform agricultural biomass waste into a durable, beneficial soil enhancer while also supporting soil improvement and climate change mitigation. Biochar is generated through the thermochemical transformation of biomass in an oxygen-limited environment. The attributes are significantly affected by the feedstock and pyrolysis parameters. Biochar typically features a porous architecture, elevated surface area, chemical resilience, surface functional groups, and cation-exchange capacity, all of which influence its interactions with soil, water, nutrients, and microorganisms. The multifunctional characteristics of biochar render it especially pertinent to climate-resilient and resource-efficient agricultural practices.

Biochar on soil physical properties

Biochar significantly improves soil physical properties, including soil structure, porosity, bulk density, aeration, and water-holding capacity. Due to its highly porous nature and low bulk density, biochar reduces soil compaction and improves soil aggregation, creating a favorable environment for root growth. Its large surface area enhances soil porosity, allowing better movement of air and water while increasing moisture retention. In hard-setting and compacted soils, biochar reduces soil strength, making tillage easier and promoting deeper root penetration. These improvements enhance soil workability, nutrient availability, and overall crop performance. However, very fine biochar particles may partially block soil pores under certain conditions, temporarily reducing water infiltration. Biochar application darkens soil colour because of its high carbon content. Darker soils absorb more solar radiation, which can increase soil temperature during cool periods and promote faster seed germination and early crop growth. The degree of darkening depends on the quantity of biochar applied, with higher application rates producing a more pronounced effect on soil colour.

Biochar on soil chemical properties

Biochar improves soil chemical properties owing to its high porosity, large surface area, and high cation exchange capacity (CEC). When incorporated into the soil, it enhances nutrient retention, water-holding capacity, and base saturation while reducing nutrient losses through leaching. Biochar also increases soil pH, making acidic soils more productive by reducing exchangeable aluminium (Al^{3+}) toxicity. In addition, it improves the availability of essential nutrients such as nitrogen, phosphorus, potassium, calcium, and magnesium, thereby enhancing fertilizer use efficiency. Biochar provides numerous adsorption sites for nutrients through charge-based interactions, helping to retain nutrients in the root zone. It also creates a favourable habitat for beneficial soil microorganisms, improving microbial activity and nutrient cycling. Collectively, these improvements enhance soil fertility, promote healthy crop growth, and contribute to sustainable agricultural production.

Biochar on Soil Biological Properties

Biochar significantly enhances soil biological properties by creating a favorable habitat for beneficial soil microorganisms. Its porous structure provides shelter and suitable conditions for the growth and multiplication of bacteria, fungi, and other beneficial microbes, leading to increased microbial biomass, activity, and soil respiration. Biochar also promotes biological nitrogen fixation and improves nutrient cycling, thereby enhancing soil fertility. In addition, it encourages the colonization of beneficial arbuscular mycorrhizal fungi and improves root nodulation in legumes, resulting in better nutrient uptake and healthier root systems. Studies have reported increased root growth, enhanced mycorrhizal colonization, improved nitrogen fixation, and higher crop yields following biochar application. Biochar strengthens soil biological health, improves soil fertility, and supports sustainable crop production by fostering a diverse and active soil microbial community.

Biochar-mediated microorganisms and soil biological health

The porous architecture of biochar can provide protected microsites for microbial colonization, while its effects on moisture, aeration, pH and nutrient availability can alter the abundance and activity of soil microorganisms. Biochar has been associated with changes in beneficial organisms such as *Bacillus*, *Pseudomonas* and arbuscular mycorrhizal fungi, which participate in nutrient cycling and plant–soil interactions. Biochar-mediated microbial processes can enhance organic-matter transformation, nutrient mineralization, biological nitrogen fixation

and rhizosphere nutrient turnover. These processes can improve nutrient acquisition and root development. However, microbial responses are not universally positive and depend on biochar composition, soil conditions and potentially inhibitory compounds formed during pyrolysis.

Biochar in Nutrient-Use Efficiency

Biochar can contribute to nutrient-use efficiency (NUE) by retaining nutrients within the root zone, reducing losses and facilitating their gradual availability to plants. Its porous structure, surface charge and cation-exchange properties provide adsorption sites for nutrient ions, while improved microbial activity promotes nutrient mineralization and cycling. Biochar is particularly valuable when integrated with organic manures, mineral fertilizers and biofertilizers rather than being considered solely as a fertilizer substitute. Such integration can improve nutrient availability, soil organic carbon and biological functioning while potentially lowering dependence on external fertilizer inputs.

Biochar enhancing water-use efficiency

Water availability is a major determinant of crop productivity under climate variability. Biochar can enhance soil-water storage and plant-available water by altering pore-size distribution and improving soil water-holding capacity. This is particularly important in coarse-textured and drought-prone soils, where water drains rapidly below the effective root zone. Improved soil-water retention allows moisture to remain available for longer periods between rainfall or irrigation events. Consequently, biochar may reduce irrigation frequency, improve irrigation water-use efficiency and buffer crops against short periods of moisture deficit.

Biochar enhances nutrient uptake and crop productivity

Biochar application improves nutrient uptake and crop productivity by increasing the availability and retention of essential nutrients such as phosphorus (P), potassium (K), and calcium (Ca). Its high cation exchange capacity and porous structure reduce nutrient losses through leaching, thereby enhancing fertilizer use efficiency. Biochar also creates a favorable environment for beneficial microorganisms, including nitrogen-fixing bacteria such as Rhizobium, which further improves nutrient acquisition by plants. Enhanced nutrient uptake promotes vigorous root growth, better plant development, and higher biomass production. Thus, biochar serves as an effective soil amendment for improving nutrient use efficiency, increasing crop yields, and supporting sustainable agricultural production.

Biochar-loaded herbicides for weed management

Biochar also has potential as a carrier material for controlled-release herbicide formulations. Its high surface area and porous architecture can adsorb herbicide molecules and regulate their release, potentially reducing rapid degradation and leaching. In the source material, biochar-loaded oxadiargyl showed greater herbicide recovery and persistence than conventional formulations. In transplanted rice, biochar-loaded oxadiargyl treatment reduced weed density and dry biomass and produced higher grain yield than conventional oxadiargyl. It indicates the potential of engineered biochar as a delivery matrix for improving herbicide-use efficiency, although such formulations require product-specific validation before field recommendation.

Biochar for environmental sustainability and climate-change mitigation

One of the most important attributes of biochar is its potential for long-term carbon sequestration. Pyrolysis converts a proportion of biomass carbon into relatively stable aromatic carbon that is resistant to rapid microbial decomposition. Incorporating this material into soil therefore transfers biomass carbon into a comparatively persistent soil-carbon pool. Biochar can also influence CO_2, CH_4 and N_2O emissions through its effects on soil carbon stabilization, aeration, redox conditions, nitrogen availability and microbial processes. In particular, adsorption and retention of nitrogen compounds can reduce leaching and volatilization and modify nitrification and denitrification processes associated with N_2O formation. Conversion of crop residues and other biomass wastes into biochar also provides an alternative to open-field burning and transforms agricultural waste into a useful resource. This links biomass-waste management with soil restoration, carbon management and circular agriculture.

Biochar for pollution mitigation

Biochar has considerable potential for soil and water remediation because its porous structure, large surface area, surface functional groups and ion-exchange capacity facilitate contaminant adsorption and immobilization. Pollutants can interact with biochar through pore filling, electrostatic attraction, ion exchange, surface complexation, precipitation and other sorption mechanisms. Biochar-based materials have been investigated for the removal or immobilization of heavy metals, pesticides, pharmaceuticals, dyes, nutrients and other emerging pollutants. This environmental function further strengthens the role of biochar as a multifunctional material connecting agricultural production with environmental remediation.

Biochar as a tool for climate-resilient agriculture

The importance of biochar in climate-resilient agriculture lies in its ability to address several production and environmental constraints simultaneously. By improving soil-water retention, nutrient conservation, microbial functioning and root-zone conditions, biochar can increase the capacity of cropping systems to withstand drought and nutrient stress. At the same time, carbon sequestration, biomass-waste recycling and potential reductions in GHG emissions contribute to climate-change mitigation. The review identifies soil amendment, contaminant immobilization, carbon storage and GHG reduction among the major environmental and agricultural functions of biochar.

Conclusion

Biochar is a versatile soil enhancer that improves soil characteristics, nutrient and water retention, microbial activity, resource-use efficiency, agricultural yield, and resilience to moisture stress. It additionally aids in carbon sequestration, the recycling of crop residues, pollution remediation, and the mitigation of greenhouse gases. Nonetheless, its efficacy depends on feedstock, pyrolysis parameters, application frequency, soil classification, crop variety, and climatic conditions. Therefore, the suitability of biochar quality and its location-specific application are crucial for establishing productive, resource-efficient, and climate-resilient agricultural systems.

References

Baiamonte, G., Minacapilli, M., & Crescimanno, G. (2020). Effects of biochar on irrigation management and water use efficiency for three different crops in a desert sandy soil. *Sustainability, 12*(18), 7678.

Bommayasamy, N., Naik, H., Chinnamuthu, C. R., Arumugam, S. R., Velusamy, K., Yeraboina, R., & Amaresan, N. (2026). Controlled-release and enhanced efficacy of a biochar-based oxadiargyl nanocomposite for sustainable weed management in transplanted rice. *Journal of Agriculture and Food Research*, *28*, 102929.

Gupta, D. K., Gupta, C. K., Dubey, R., Fagodiya, R. K., Sharma, G., Keerthika, A., Noor Mohamed, M. B., Dev, R., & Shukla, A. K. (2020). Role of biochar in carbon sequestration and greenhouse gas mitigation. In J. S. Singh & C. Singh (Eds.), *Biochar Applications in Agriculture and Environment Management* (pp. 141–165). Springer Nature Switzerland AG.

Jaswal, A., Mehta, C. M., Singh, A., Kumar, A., & Jayanthi, J. (2026). Biochar-based integrated nutrient management improves soil quality and biological functioning in a rice–wheat cropping system. *Discover Sustainability*, *7*, 1132.

Laishram, D., Kim, S.-B., Lee, S.-Y., & Park, S.-J. (2025). Advancements in biochar as a sustainable adsorbent for water pollution mitigation. *Advanced Science*, *12*, 2410383.

Nazim, M., Ghafoor, A., Hussain, A., Tabassum, M., Nawaz, A., Ahmad, M., Muhammad, M., & Ali, M. (2025). Biochar as a climate-smart agricultural practice: Reducing greenhouse gas emissions and promoting sustainable farming. *Phyton-International Journal of Experimental Botany*. 9491): 65-98.



Volume: 06 Issue No: 09

ILLEGAL CULTURE AND SALE OF AFRICAN CATFISH (*CLARIAS GARIEPINUS*) IN INDIA: ENVIRONMENTAL AND PUBLIC HEALTH IMPLICATIONS

Article ID: AG-VO6-I09-131

Syed Hamza Syed Saidoddin*[1], Abhinav Ashok Vaichalkar[1], Sadananda Namdev Kambale[1], and Shyam Datta Waghmare[1]

[1]Department of Fisheries, Government of Maharashtra, India

*[2]Sharda School of Smart Agriculture, Sharda University, Agra, Uttar Pradesh (282 007), India

*Corresponding Author: Syed Hamza Syed Saidoddin

Abstract

The culture and sale of African catfish (*Clarias gariepinus*), commonly known as exotic magur, have raised significant ecological, regulatory, and public health concerns in India. Although the species is valued for its rapid growth, air-breathing capacity, and tolerance to adverse environmental conditions, its unauthorized introduction and cultivation may threaten native aquatic biodiversity through predation, competition, and habitat interactions. The escape of cultured individuals into natural water bodies can further contribute to the establishment and spread of invasive populations. Illegal farming and marketing practices may also involve poor water-quality management, unregulated feed materials, and inadequate food-safety measures, potentially increasing the risk of microbial contamination and chemical accumulation. In response to these concerns, Indian authorities and judicial bodies have implemented restrictions on the breeding, culture, transportation, and sale of exotic African catfish and its hybrids. However, enforcement remains challenging because of illegal trade, inadequate monitoring, and difficulties in distinguishing exotic *C. gariepinus* from indigenous *Clarias batrachus*. This review discusses the ecological impacts, legal restrictions, trade-related challenges, and potential public health concerns associated with African catfish culture and marketing. It emphasizes the importance of effective enforcement, species identification, environmental monitoring, food-safety testing, and promotion of sustainable native fish culture.

Keywords: African catfish, *Clarias gariepinus*, exotic magur, illegal culture, fish trade, invasive species, biodiversity, public health.

1. Introduction

Clarias gariepinus (Burchell, 1822), commonly known as African catfish, is an air-breathing freshwater species valued in aquaculture for its rapid growth, tolerance of low dissolved oxygen, and ability to survive under variable environmental conditions. These characteristics can also facilitate its establishment outside its native range when introduced without adequate controls.

In India, the culture and breeding of exotic African catfish and its hybrids have been prohibited through government directions and judicial interventions. The National Green Tribunal's orders distinguish the prohibited exotic *C. gariepinus* from the indigenous *Clarias batrachus*, which is not subject to the same blanket prohibition.

The ecological concern is associated with the species' feeding behaviour, environmental tolerance, potential competition with native fish, and the possibility of escape from aquaculture facilities into natural water bodies. However, the magnitude of these effects varies with habitat, population density, food-web structure, and local environmental conditions.

2. Ecological Threats and Biodiversity Impacts

2.1 Predation and Food-Web Interactions

C. gariepinus is an opportunistic feeder whose diet can include fish and other aquatic organisms. Its introduction may alter food-web relationships through predation and competition.

A modelling study conducted in the Karapuzha Reservoir, India, reported substantial ecological effects associated with *C. gariepinus*, including high niche overlap and adverse mixed trophic impacts on several fish and crustacean groups (Khan et al., 2021). However, modelling results should be interpreted as ecosystem-specific evidence rather than proof that identical impacts occur in every reservoir.

2.2 Competition and Displacement of Native Species

The establishment of African catfish may increase competition for food and habitat with native species. Its effects can be especially important in ecosystems where resources are limited or where native fish have overlapping feeding niches.

Research from Mattupetty Reservoir, Kerala, documented the occurrence of *C. gariepinus* alongside other invasive fish and reported dietary observations, including cannibalism and

predation on other fish. The authors discussed the possibility of displacement of indigenous species in the invaded reservoir system (Raj et al., 2021).

The claim that *C. gariepinus* has caused the near-extirpation of *C. batrachus* should be removed unless supported by a specific population study demonstrating this relationship.

2.3 Environmental Tolerance and Spread

African catfish possesses accessory respiratory adaptations that allow it to tolerate low-oxygen conditions. This physiological characteristic may facilitate survival in degraded or seasonally unsuitable habitats.

The documented occurrence of *C. gariepinus* in the Vembanad Lake system was associated with escape from unregulated aquaculture facilities. The study highlighted the potential for the species to spread into natural aquatic ecosystems and recommended management attention (Krishnakumar et al., 2011).

Although the species has considerable environmental tolerance, its ability to move across land, survive pollution, and establish populations should be assessed using evidence from the specific habitat under consideration.

2.4 Pathogens and Disease Transmission

Introduced fish may carry parasites or infectious organisms that affect native species. Nevertheless, the statement that *C. gariepinus* has frequently caused novel pathogen outbreaks and mass mortality events in India requires specific epidemiological evidence.

Accordingly, disease-related risks should be investigated through:

- Parasite screening
- Microbiological testing
- Quarantine procedures
- Health certification
- Monitoring of native fish populations

3. Public Health Risks and Bioaccumulation

3.1 Unregulated Culture Conditions

Unregulated fish farming may involve inadequate water-quality management, poor sanitation, unsuitable feed, and insufficient disease control. However, these conditions cannot be assumed to occur in every African catfish production unit.

The Indian literature has documented the use of slaughterhouse waste, poultry waste, and other unconventional feed inputs in some unauthorized culture systems. Singh et al. (2014) discussed possible environmental and health risks associated with these practices, including concerns regarding lead contamination.

3.2 Hazardous Feed and Potentially Toxic Metals

The use of contaminated feed or polluted water can introduce potentially toxic elements, including lead, cadmium, and mercury, into aquaculture systems. The extent of accumulation depends on the source and concentration of contaminants, exposure duration, fish size, tissue type, and environmental conditions.

The presence of heavy metals in fish should therefore be established through laboratory analysis rather than inferred solely from the use of waste-based feed. Studies from Nigeria have reported metal residues in *C. gariepinus*, but findings from other countries cannot automatically be applied to Indian fish populations (Abdullahi & Daniel, 2025).

3.3 Food Safety

Fish obtained from unregulated sources may present food-safety concerns when water, feed, handling, or storage conditions are poor. Potential hazards include microbial contamination and chemical residues.

However, it is scientifically inappropriate to state that all illegally cultured African catfish contain dangerous concentrations of heavy metals or pathogens. Food-safety conclusions should be based on validated testing and comparison with applicable regulatory limits.

4. Legislative Framework and Enforcement Challenges in India

4.1 Prohibition of Exotic African Catfish

The National Green Tribunal, in its order dated **22 January 2019** in *Hussain Khan v. Fisheries Department & Ors.* and connected matters, recorded that breeding and culture of exotic African catfish (*Clarias gariepinus*) and its hybrids were prohibited in all States and Union Territories. The order also directed action concerning existing stocks.

The Tribunal's subsequent proceedings addressed difficulties in distinguishing prohibited exotic African catfish from indigenous *Clarias batrachus*. Accurate species identification is therefore an important requirement for enforcement and for preventing wrongful action against farmers cultivating permitted native species.

4.2 Enforcement Challenges

Enforcement may be complicated by:

- Similar physical appearance of native and exotic catfish
- Illegal movement of live fish
- Escape from poorly secured ponds
- Limited inspection capacity
- Inadequate species-identification facilities
- Continued market demand

These challenges support the need for coordinated enforcement, public awareness, reliable identification protocols, and cooperation between fisheries departments, research institutions, farmers, and local communities.

5. Management Recommendations

The following measures may support the prevention and management of African catfish invasions:

1. **Strengthen enforcement:** Implement regular inspections of aquaculture facilities, markets, and fish-transport routes.
2. **Improve species identification:** Use morphological keys and, where necessary, molecular identification to distinguish *C. gariepinus* from *C. batrachus*.
3. **Prevent escape:** Improve Pond security, screening, drainage management, and flood protection.
4. **Monitor natural water bodies:** Conduct surveys in reservoirs, wetlands, rivers, and estuaries where escape or unauthorized release is suspected.
5. **Improve feed safety:** Promote approved feed materials and monitor contaminants in feed and culture water.
6. **Promote native species:** Support the culture and marketing of legally permitted indigenous fish species.
7. **Develop community awareness:** Educate farmers, traders, and consumers about species identification, legal requirements, and ecological risks.

Eradication activities should be conducted by authorized agencies using scientifically appropriate methods and should avoid unintended harm to native fish and other aquatic organisms.

Conclusion

The introduction and unauthorized culture of *Clarias gariepinus* present potential ecological and management concerns in India, including predation, competition with native fish, escape into natural water bodies, and difficulties in regulatory enforcement. Research from Indian reservoirs and wetlands provides evidence that the species can influence food-web interactions and establish populations outside controlled culture systems (Krishnakumar et al., 2011; Khan et al., 2021).

The legal prohibition of exotic African catfish and its hybrids provide a regulatory basis for controlling their culture and spread. However, effective implementation requires accurate species identification, systematic monitoring, responsible aquaculture practices, and coordination among enforcement agencies and local communities.

Public-health claims concerning heavy metals and pathogens should be supported by laboratory-based evidence from specific production and marketing locations. A scientifically sound management strategy should therefore combine ecological monitoring, food-safety testing, legal enforcement, and support for sustainable native fisheries.

References

Khan, M. F., Panikkar, P., Salim, S. M., Leela, R. V., Sarkar, U. K., Das, B. K., & Eregowda, V. M. (2021). Modeling impacts of invasive sharp tooth African catfish *Clarias gariepinus* (Burchell 1822) and Mozambique tilapia *Oreochromis mossambicus* (Peters, 1852) on the ecosystem of a tropical reservoir ecosystem in India. *Environmental Science and Pollution Research, 28*, 58310–58321.

Krishnakumar, K., Ali, A., Pereira, B., & Raghavan, R. (2011). Unregulated aquaculture and invasive alien species: A case study of the African catfish *Clarias gariepinus* (Burchell, 1822) in Vembanad Lake (Ramsar Wetland), Kerala, India. *Journal of Threatened Taxa, 3*(2), 1737–1744.

Singh, A. K., Ansari, A., Srivastava, S. C., & Shrivastava, V. K. (2014). An appraisal of introduced African catfish *Clarias gariepinus* (Burchell 1822) in India: Invasion and risks. *Annual Research & Review in Biology, 6*(1), 41–58.

Raj, S., et al. (2021). Food spectrum of two co-occurring invasive fish, *Cyprinus carpio* Linnaeus, 1758 and *Clarias gariepinus* (Burchell, 1822) in Mattupetty Reservoir, Kerala, India. *Indian Journal of Fisheries.*

National Green Tribunal. (2019, January 22). *Hussain Khan v. Fisheries Department & Ors. and connected matters*, Original Application No. 435/2018. Order concerning the prohibition of exotic African catfish (*Clarias gariepinus*) and its hybrids in India.

National Green Tribunal. (2024, April 1). *Maa Durga Primary Fisherman Co-operative Society Ltd. v. Ministry of Fisheries, Animal Husbandry and Dairying & Ors.*, Original Application No. 118/2024. Proceedings concerning clarification of the prohibition on exotic magur and identification of native and exotic catfish.

Abdullahi, S. A., & Daniel, R. J. (2025). Comparative study of heavy metals in wild catfish (*Clarias gariepinus*) from Jabi Lake and cultured catfish from Gwagwalada fish market Abuja. *Science World Journal*, *19*(4), 951–954.

Volume: 06 Issue No: 09

POTENTIAL CANDIDATE FISH SPECIES FOR DECLERATION OF STATE FISH OF ASSAM, NORTHEAST INDIA

Article ID: AG-VO6-I09-132

Barasha Baishya[1], Avinash Talukdar[1], Pabitra Kumar Saharia[1], Rubina Parbin[1], Jyotismita Thakuria[1]

[1]Department of Aquaculture, Faculty of Fisheries Science, Assam Veterinary and Fisheries University, Raha, Assam, India

*Corresponding Author: Barasha Baishya

Abstract

Assam, situated within the globally recognised Himalaya and Indo-Burma biodiversity hotspots, harbours an exceptionally rich freshwater ichthyofauna sustained by the Brahmaputra and Barak river systems and their associated floodplain wetlands, locally called beels. Despite this diversity, and despite a conservation-oriented "state fish" initiative launched by the ICAR–National Bureau of Fish Genetic Resources (NBFGR) in 2006—under which sixteen Indian states have already notified a state fish—Assam is yet to declare one of its own. This review compiles the rationale, guidelines and criteria prescribed by NBFGR for selecting a state fish and evaluates ten native candidate species-*Chitala chitala, Wallago attu, Sperata seenghala, Clarias magur, Channa barca, Ompok pabo, Channa striata, Cirrhinus reba, Hemibagrus menoda and Cyprinion semiplotum* against these criteria, considering their distribution, IUCN and NBFGR conservation status, and their ecological, economic, cultural and aquaculture significance. The article also outlines ongoing in-situ and ex-situ conservation measures, including Assam's own Gene Bank for Indigenous Fish (GBIF) programme, and argues that formal declaration of a state fish would strengthen conservation-linked research, aquaculture development and public awareness in the state.

Keywords: State fish; Assam; IUCN Red List; NBFGR; conservation; freshwater fish; Northeast India

Introduction

The northeastern region is the easternmost region of India, extending between latitudes 21°57′ and 29°30′ N and longitudes 89°46′ and 97°30′ E. Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura are the eight landlocked states that together constitute one of India's richest regions in terms of biodiversity and natural resources, although the soils here are slightly acidic in nature. Physio-graphically, the region is categorized into the Patkai, Brahmaputra and Barak valley plains and the Eastern Himalaya. The two main river systems of the region are the Brahmaputra in the north and the Barak (Meghna), which runs through the southern edges, together with their numerous tributaries. The Brahmaputra and Barak rivers, along with their tributaries, contribute over 50% of India's water resources. The area is rich in freshwater fish species and is regarded as one of the world's hotspots for freshwater fish biodiversity, with northeast India representing approximately 33% of the 2,163 freshwater fish species recorded from India. Goswami et al. (2012) listed about 422 fish species from northeast India, belonging to 133 genera and 38 families, including both indigenous and exotic species, while Vishwanath (2017) later reported 318 fish species from the region. The maximum diversity is observed in the family Cyprinidae, represented by 154 species. Assam alone accounts for 311 of these species, of which 131 have food value and 180 have ornamental value. A variety of farmed species are cultured across the northeastern region, with Indian major carps and Chinese carps forming the major cultivated species and contributing the most to production; mahseer and trout are the two notable coldwater species also brought under culture.

The Brahmaputra and Barak river systems, together with their tributaries and floodplain wetlands locally known as beels provide a highly conducive habitat for an array of fish species. Some important ornamental fish genera of Assam include Colisa (gouramis, e.g. Trichogaster spp.), Nemacheilus (loaches, e.g. Schistura spp.), Danio (danios, Danio spp.), Botia (loaches, Botia spp.) and Chaca (angler catfish, *Chaca chaca*). Among the commercially important food fishes of Assam are Rou/Rohu (Labeo rohita), Bhokua/Catla (*Catla catla*), Pabho/Pabda (*Ompok pabda*), Chital (*Chitala chitala*), Magur (*Clarias magur*), Singhi (*Heteropneustes fossilis*) and Sol (*Channa striata*). Today, the NE region is estimated to harbour more than 500 fish species with a high level of endemism. Although it is difficult to precisely enumerate the threatened species of NE India, several studies point to a rapid decline in their numbers, with some facing extinction; species such as *Channa barca, Channa aurantimaculata*, and members of the genera

Ompok and related species require immediate protection and conservation. Several catfish species have also declined drastically due to natural and man-made causes, degradation of the aquatic environment, and the shrinking of wetlands and water bodies. According to the compilation of threatened freshwater fishes of India by NBFGR (Lakra et al., 2010), catfishes of conservation concern from the Brahmaputra-Barak system include *Sperata seenghala, Ompok pabda, Ompok bimaculatus, Bagarius bagarius, Clupisoma garua, Silonia silondia, Hemibagrus menoda and Rita rita*, several of which have declined due to overfishing, habitat degradation and loss of breeding grounds. *Sperata seenghala* in particular has already been declared endangered in some countries (IUCN, 1998). These factors have created a serious problem for the genetic resources of these species, and there is an urgent need to develop suitable methods for bringing such prized catfishes under culture fisheries in impounded water bodies. At present, only about 12 fish species are commercially bred and cultured in the Northeast; conserving the genetic resources of the remaining wild species is therefore essential for their potential future use in aquaculture.

In-situ conservation of fish germplasm refers to the maintenance of species within their natural habitats and has been pursued in the region through habitat and wetland protection, community-based conservation of breeding grounds and seasonal fishing restrictions during the spawning period. Ex-situ conservation complements these efforts through live gene banks, captive brood-stock development and cryopreservation of sperm, eggs and embryos, allowing the genetic material of threatened species to be preserved outside their natural environment. At the national level, ICAR-NBFGR maintains live gene banks across the country's major biodiversity zones and has developed cryopreservation protocols for the milt of several indigenous species as part of its ex-situ conservation and germplasm-registration programme. In Assam, this approach has been operationalised through the Gene Bank for Indigenous Fish (GBIF), implemented by the State Fisheries Department as the Scientific Conservation Programme for Indigenous Fishes (SCoPIF) in partnership with the College of Fisheries, Raha (Assam Agricultural University), since 2018-19. The programme focuses on assessing the status of ichthyofaunal diversity in the Brahmaputra and Barak valleys, developing captive-breeding and culture technologies for threatened indigenous fishes, establishing a live gene bank, and raising mass awareness for the in-situ conservation of indigenous fish germplasm. Such combined in-situ and ex-situ measures, together with a formally declared state fish, would substantially strengthen the long-term

conservation of Assam's fish genetic resources. In this regard, NBFGR has put forward the concept of a state fish, along with certain guidelines and criteria for its selection.

The IUCN Red List Categories

The International Union for Conservation of Nature (IUCN) Red List of Threatened Species, also known as the IUCN Red List or Red Data Book, was founded in 1964 and is the world's most comprehensive inventory of the global conservation status and extinction risk of biological species. Species are assessed and placed into categories on the basis of quantitative criteria such as population size, rate of population decline, extent and degree of fragmentation of geographic distribution, and probability of extinction in the wild, following guidelines developed by the IUCN Species Survival Commission; each assessment is, wherever possible, reviewed and updated every five to ten years. On this basis, species are classified into nine categories arranged in order of increasing extinction risk: Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD) and Not Evaluated (NE). Species falling under the Critically Endangered, Endangered and Vulnerable categories are collectively referred to as "threatened"; it is these categories, together with Near Threatened and Data Deficient status, that are most relevant while evaluating candidate species for state fish declaration, since they flag populations most in need of conservation attention.

Guidelines for Selection of State Fish

The guidelines for choosing the "state fish" are based entirely on the preference of the concerned state government, taking into account regional importance and utility to stakeholders. The declaration of a state fish involves various departmental processes (both inter- and intra-departmental) linking multiple entities such as research organizations, line departments, stakeholders and policymakers. The major steps involved in the process include: (i) initiation by ICAR–NBFGR, informing the respective state fisheries department of the importance of the state fish concept and requesting them to consider declaring a state fish; (ii) identification/recommendation of potential indicative species with conservation, endemism, ecological, economic or aquaculture importance; (iii) profiling the characteristics of the fishes, including taxonomic position, distribution, abundance, biology, economic demand, nutritional and medicinal benefits, and cultural significance; (iv) collection of stakeholders' perceptions through deliberations with fishermen, fish farmers, consumers, anglers, field assistants,

conservationists, researchers and policymakers; (v) envisioning the possible benefits and future developments of the selected fish; (vi) assessing the feasibility of implementing management measures for conservation, sustainable utilization and aquaculture development; (vii) choosing the fish for declaration by the respective state government; (viii) declaring it through official notification and communicating it to the general public through mass media; and (ix) formulating and implementing strategies for the holistic development of fisheries in the state.

Criteria for Selection of State Fish

"Conservation" forms the central pillar of the selection criteria, along with other themes, namely local preference and popularity; ecological, economic, cultural, historical and culinary importance; endemism; and aquaculture potential.

Current Status of State Fish Species

ICAR–NBFGR first proposed the state fish concept in 2006, and since then sixteen Indian states have notified and declared a state fish, while several others continue the process (Table 1).

State	**State Fish (common/local name)**	**Scientific name**
Arunachal Pradesh	Golden mahseer	*Tor putitora*
Himachal Pradesh	Golden mahseer	*Tor putitora*
Jammu & Kashmir	Golden mahseer	*Tor putitora*
Uttarakhand	Golden mahseer	*Tor putitora*
Uttar Pradesh	Chitala / Clown knifefish	*Chitala chitala*
Haryana	Black rohu	*Labeo calbasu*
Manipur	Pengba	*Osteobrama belangeri*
Tripura	Pabda	*Ompok pabda*
Meghalaya	Chocolate mahseer	*Neolissochilus hexagonolepis*
Nagaland	Chocolate mahseer	*Neolissochilus*

State	State Fish (common/local name)	Scientific name
		hexagonolepis
Sikkim	Katley / Copper mahseer	*Neolissochilus hexagonolepis*
West Bengal	Hilsa	*Tenualosa ilisha*
Odisha	Mahanadi calbasu	*Labeo calbasu*
Kerala	Karimeen / Pearl spot	*Etroplus suratensis*
Karnataka	Carnatic carp	*Hypselobarbus carnaticus*
Andhra Pradesh	Murrel	*Channa striata*

Table 1. Illustrative list of Indian states and their declared state fish, compiled from ICAR–NBFGR communications and state government notifications

Before a state formally declares its state fish, it is worth considering why such a declaration would matter for Assam in particular. Assam supports one of the richest and most economically important inland fisheries in the country: fish is a dietary staple for over 90% of its population, and the state's more than 2,000 beels serve as vital breeding and nursery grounds for numerous riverine species. Yet several of Assam's native and economically valuable fishes showing signs of decline due to overfishing, habitat degradation, wetland encroachment and the indiscriminate use of fine-mesh nets. A formally declared state fish would (i) provide a visible conservation flagship around which research, breeding programmes and public awareness can be organised; (ii) direct policy and funding support towards the species' captive breeding, ranching and habitat restoration, as has already been done for *Chitala chitala* in Uttar Pradesh; (iii) strengthen the identity and cultural branding of the state's fisheries sector; and (iv) create aquaculture and livelihood opportunities for fish farmers through promotion of a high-value indigenous species, reducing dependence on exotic carps alone. Following the overwhelming response to, and acceptance of, the state fish concept elsewhere in the country, Assam may also come forward to consider declaring its own state fish for the conservation and promotion of sustainable fisheries management.

Potential Fish species that can be suggested for declaration as State fish of Assam (priority wise, based on the criteria given by NBFGR) –

1. *Chitala chitala*

Local name – Chital

Distribution: Indus, Ganges-Brahmaputra and Mahanadi River basins in India.

IUCN Red List Status: Near Threatened category

NBFGR, 2010: Endangered

Significance according to criteria given by NBFGR:

The fish is highly preferred and has strong popularity among local communities. The species holds significant economic importance due to its high demand in commercial markets. It carries deep cultural significance, playing an essential role in traditional ceremonies and regional cuisine. As a native species, it maintains vital ecological balance within its natural river habitats. The fish offers strong aquaculture potential because its commercial breeding technology is already widely adopted. It retains historical importance through its symbolic links to traditional community fish-catching festivals. The species is highly prized for its exceptional culinary value and distinct taste profile.

2. *Wallago attu*

Local name – Borali

Distribution: Brahmaputra and Ganges River system

IUCN Red List Status, 2019: Vulnerable

Significance according to criteria given by NBFGR:

The fish holds substantial economic importance, serving as a highly prized and premium delicacy among Assamese fish consumers. It is suitable for commercial culture practices. As a top predator in its environment, the species performs a vital ecological function by regulating aquatic populations and maintaining natural balance. Embedded in regional traditions, the fish is a staple in Assamese festivals and is frequently used in religious offerings. It is recognized as a heritage fish of historical importance, carrying deep-rooted connections to the legendary history of Jungal Balahu. The mighty river Brahmaputra serves as the prime native habitat critical to the survival of this species.

3. *Sperata seenghala*

Local name: Aari

Distribution: Brahmaputra and Barak River systems are among its natural habitats.

Significance according to criteria given by NBFGR:

It stands out as one of the most desired large riverine species, driving both market popularity and economic value. It enjoys high commercial status and is preferred as food fish due to its excellent flesh quality, flavour and taste. The species plays a vital role in supporting the livelihoods of floodplain and riverine communities. It serves as a crucial indicator of, and contributor to, healthy river ecosystems. It holds deep cultural value, frequently featuring in local festivals and religious offerings. The species is highly compatible with controlled culture in pond environments, presenting strong opportunities for fish farming.

4. *Clarias magur*

Local name – Magur

Distribution: Ganga and Brahmaputra river basins of northern and northeastern India

Significance according to criteria given by NBFGR:

This highly priced and much sought-after species offers considerable economic potential for small-scale aquaculture farmers. Its high market price makes it a prized catch and a lucrative choice for sustainable farming. It has occupied a place of priority among local communities for its nutritional and medicinal value. The species plays an essential role in sustaining the delicate ecosystems of wetlands and seasonal paddy fields. It demonstrates strong viability and promise for commercial cultivation within managed aquaculture systems, and it frequently appears in local folktales and serves as a staple in traditional healing practices. It is highly regarded for its distinct culinary appeal and nutritional contribution to regional diets.

5. *Channa barca (Goroka/Pipli seng)*

Distribution: Brahmaputra River system

IUCN Red List Status, 2009: Data Deficient

NBFGR, 2010: Endangered

Recently listed under Schedule II of the Wildlife (Protection) Amendment Act, 2022 of India

Significance according to criteria given by NBFGR:

It is a rare, localized, commercially important fish species associated with the Brahmaputra basin, making it important for regional biodiversity. Its limited geographical range makes the species particularly important for conservation and habitat protection. It is well known locally

and can be considered part of Assam's traditional aquatic biodiversity and heritage. Channa barca has ornamental value and is also traditionally regarded as having medicinal importance. Its presence can indicate the condition and ecological health of wetland habitats, making it a useful bioindicator. Its occurrence in selected protected areas of Assam highlights the need for habitat conservation, monitoring and protection from overexploitation.

6. *Ompok pabo (Pavo)*

Distribution: Ganga-Brahmaputra river system in northeast India and Bangladesh

IUCN Red List Status, 2009: Near Threatened

NBFGR, 2010: Endangered

Significance according to criteria given by NBFGR:

The species holds significant consumer demand and is widely favoured as a staple seafood item commonly found throughout local fish markets. It plays a vital role in maintaining biodiversity and ecosystem balance, being inherently native to regional rivers, beels and natural wetlands. The fish commands a premium market price, making it highly valuable for boosting the income and livelihoods of commercial fishers and traders. It exhibits excellent growth traits and adaptability, making it a highly viable candidate for controlled commercial farming and mass production. The species also carries regional heritage, traditional folklore and a long-standing history among local communities, and it is highly celebrated for its distinct flavour profile and excellent nutritional benefits within traditional cooking practices.

7. *Channa striata (Sol maas)*

Distribution: India, Sri Lanka, Nepal, Bangladesh and other South Asian countries

IUCN Red List Status, 2019: Least Concern

Significance according to criteria given by NBFGR:

The species is highly valued for its medicinal properties among local communities and is commonly available in local markets and rural fish harvests. It provides good income and livelihood opportunities for fishers and contributes to maintaining the ecological balance of Assam's wetlands. It is an integral part of traditional Assamese cuisine and food practices, traditionally associated with inland fishing and rural livelihoods, and it has strong potential for culture owing to its demand and economic value.

8. *Cirrhinus reba (Lachim bhangon)*

Distribution: NE India – all the NE states except Nagaland; also Bangladesh, India (Ganga-Brahmaputra river basin), Myanmar, Nepal and Pakistan.

IUCN Red List Status, 2010: Least Concern

Significance according to criteria given by NBFGR:

The species is highly preferred and popular among local consumers, giving it substantial commercial and economic importance. It is a species indigenous to the river systems and wetlands of Assam, playing a vital role in maintaining local aquatic ecosystems. The fish holds high potential for aquaculture, backed by breeding technologies that actively support the livelihoods of local fishing communities.

9. *Hemibagrus menoda (Gagol)*

Distribution: Brahmaputra and Ganga River system

IUCN Red List Status, 2009: Least Concern

Threatened Fishes of India, NBFGR 2010: Endangered

Significance according to criteria given by NBFGR:

The species has high economic importance, commanding premium prices in many rural and urban fish markets of Assam. It is locally rare in many parts of Assam and is extremely sensitive to environmental disruption; its presence indicates clean, well-oxygenated river habitats. It is deeply integrated into traditional Assamese cuisine and local identity, and it forms a vital, long-established component of the native Brahmaputra river food web.

10. *Cyprinion semiplotum (Assamese king fish)*

Distribution: Brahmaputra River system

IUCN Red List Status, 2009: Vulnerable

NBFGR, 2010: Vulnerable

Significance according to criteria given by NBFGR:

The species is strictly endemic to the upper reaches of the Brahmaputra River system. It holds a high preference and significant cultural value among local hill and tribal communities and is recognized as a key symbol of aquatic heritage. Functioning as a vital bioindicator species, it serves as a metric for ecosystem health within upland rivers and foothill zones. It demonstrates substantial commercial potential for both coldwater aquaculture development and the ornamental trade.

Conclusion

Beyond the choice of species, this article underscores that a state fish must be sustained in-situ and ex-situ conservation action including wetland and breeding-ground protection, closed seasons, live gene banks, cryopreservation of germplasm, and continued support to programmes such as Assam's Gene Bank for Indigenous Fish. Taken together, the formal declaration of a state fish for Assam, backed by these conservation measures and by targeted aquaculture development, would help secure the genetic resources of the state's indigenous fishes, strengthen livelihoods in the fisheries sector, and build public pride and awareness around Assam's exceptional aquatic biodiversity. It is recommended that the state fisheries department, in consultation with ICAR–NBFGR, researchers and local stakeholders, move forward with the formal notification of a state fish at the earliest, using the criteria and candidate species profiles.

Volume: 06 Issue No: 09

ENDIVE- A VALUABLE UNDERUTILIZED LEAFY SALAD VEGETABLE

Article ID: AG-VO6-I09-133

[1]V. Kanthaswamy, [1*]V. Krishnan, [1]M. S. Marichamy, [2]B. Bavithra, [3]S. Priyanga and [3]N. Bavya

[1]Faculty, [2]Ph. D. Scholar & [3]PG Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author: V. Krishnan

Introduction

Endive, botanically called *Cichorium endivia* var. *Endivia*, belonging to Asteraceae family with 2n = 18, is a bitter, crunchy leaf vegetable from the chicory family. It most commonly appears as the white, oblong Belgian endive with light green ends or the slightly milder red endive. Endive is best enjoyed with sweet, creamy or acidic foods to balance out its bitter taste. It's common to serve endive as an appetizer with something on top of it.

ORIGIN AND DISTRIBUTION

Endive was probably grown first in South Asia in Mediterranean region, where the wild relatives of endive, *i.e.*, *Cichorium pumilum* and *Cichorium calvum* are found growing. Hence, both the species can be considered as the progenitor of endive. *Cichorium endivia* was probably known to the old Egyptians but no archaeological evidence has been found. It spread to Central Europe in the sixteenth century and is now grown throughout Europe and North America. It is also grown throughout the tropics including tropical Africa though it is mostly of minor importance there.

BOTANICAL DESCRIPTION

Endive is an annual or biennial erect herb up to 170 cm tall producing taproot and rosette of large leaves when young, forming a loose head. Leaves are alternate, simple or pinnatifid, sessile, broad measuring 45 × 18 cm, slightly crumpled, margin entire or dentate (escarole type) or very narrow, deeply pinnatifid and strongly curled (curly leaved type), progressively smaller

upwards on stem, slightly pubescent or glabrous, pale to dark green or yellowish and sometimes reddish along midrib. Inflorescence is a head, sessile or on up to 20–cm-long apically thickened peduncle, involucres with outer row of five bracts (7–10 × 2–5 mm) and inner row of eight bracts (8–12 × 1–3 mm).






Flowers are 15–20 per head, all ligulate, corolla up to 2 cm long, blue, sometimes white, five-lobed at apex, stamens five with anthers fused into a tube, ovary inferior, single-celled, style slender and hairy with two slender stigmatic lobes. Fruit is an obovoid to cylindrical achene (2–3 × 1–1.5 mm) and brown with pappus of one to three rows of small persistent membranous scales. Endive forms a dense rosette of leaves in the first year. Upon bolting, the stem elongates and becomes branched. The inflorescence bears many heads. Flowers usually open only in the morning and wither after about 6 hours. Most of the cultivars are self-pollinating but some of the cultivars are cross-pollinated by insects.

CULTIVATED VARIETIES

There are three types of endive, *viz*.,

(i) **Upright Batavian or escarole**: With large broad leaves.

(ii) C**urly or fringed Frisee (*Cichorium endivia* var. *crispum*):** With a rosette of delicately serrated leaves. Curly varieties are used for summer cropping. Its outer leaves can be cooked as greens

(iii) **Broad-leaved types or Cutting type (*Cichorium endivia* var. *latifolia*):** These are robust and useful for winter cropping.



Upright Batavian



Curly or Fringed Frisee



Broad leaved type

The other popularly grown varieties are given below:

Wallone AGM: A high-yielding variety with large, vigorous, green, finely cut leaves is good for cuttings and it gives more cuttings.

Despa AGM: An attractive Frisee type variety is resistant to bolting.

Frenzy AGM: A variety with compact and uniform finely cut leaves is used in top restaurants.

Lassie AGM: A well-flavoured high-yielding variety has very deeply cut leaf.

CLIMATE AND SOIL

Both the species of endive are easy to cultivate. They are more tolerant of high temperature than lettuce and can be grown from cool temperate areas to tropical lowlands, though in the tropics, better results are obtained above 500 m altitude. It can tolerate mild frost but the optimum temperature for its growth is 15–18°C. At high temperatures, the leaves become fibrous. Endive requires long days for flowering and rarely flowers in the tropics. Vernalisation in some cultivars at temperature below 10°C gives an additional stimulus to flowering. The endive crop is more tolerant of heat than lettuce.

Endive prefers loose and deep soils that are sufficiently fertile, especially the top 20-cm layer, so that the roots may be able to penetrate the soil to a depth of at least 30 cm. The most

preferable pH of the soil is 6.5–7.8. Unlike most other root crops, mildly stony soil is also acceptable. The forking affects the roots quality but does not necessarily affect the chicon quality. The soil should be free from previously grown crop residues, as they hamper the penetration of roots into soil, which causes forking. Incorporation of fresh manure should also be avoided due to the amount of available nitrogen that causes excessive leaf growth.

SEASON AND SOWING

The endive seeds are sown as early as 4–6 weeks before the average date of last frost in spring. The seeds for raising seedlings indoors can be sown 8–10 weeks before the average last frost. The sowing time is so adjusted that the crop may become ready for harvest before the temperature reaches higher than 30°C. The crop is sown successively after every 2 weeks beginning in midsummer. In mild-winter regions, endive is grown in autumn, winter and spring. The seed rate depends on viability, soil fertility, irrigation facilities available and growing season. The seed of endive is very small, having test weight of 1.3–1.6 g. About 500 g seed is required for planting a hectare area.

Endive is one of the most difficult vegetables to grow, requiring a two-step growing process before it is ready for harvesting. As usual, it is propagated by seed. If the seeds are to be sown in a nursery, six seeds are sown per 30 cm row made 45 cm apart, or three rows may be adjusted on a 1.5-m wide bed. The seeds are sown at a depth of 6 mm and 2.5–5 cm apart in a row at a distance of 45–60 cm. Thinning is an important operation because overcrowded seedlings may develop seed stalk. Thus, after emergence, the seedlings are thinned to 5 cm apart. In heavy soils, it is always safe to sow seeds when the soil contains enough moisture for seed germination. Seedlings become ready for transplanting about 1 month after sowing, when they have four to six true leaves. At this stage, they are transplanted in the field where the first growth takes about 150 days, where the chicory grows from seed into a leafy green plant with a deep taproot. The planting distance is maintained as 25–40 × 25–40 cm with the widest spacing for broad-leaved cultivars. Dense planting favours self-blanching but increases the risk of rot. At harvest, the tops of the leafy chicory plant are cut off and then the roots are dug up and placed in cold storage where they enter a dormancy period. As the demand necessitates, the roots are taken out from the cold store for their second growth, which takes 28 days in dark, cool and humid forcing rooms, similar to a mushroom growing facility. Control over the initiation of this second growing process allows for the year-round production of endive.

MANURES AND FERTILIZERS

For adequate nutrients supply, the soil from the field is analysed for chemical composition. Nitrogen rates may need to be adjusted depending on crop, planting date, soil type and weather conditions. Based on the analysis, nitrogen may be applied at 50–100 kg, phosphorus 100–150 kg and potassium 50–150 kg/ha. Full dose of phosphorus and potash along with half dose of nitrogen is applied at the time of sowing or transplanting preferably by placing 5 cm to the sides and 5 cm below the seed or plant roots and rest of the nitrogen is applied in two split doses, *i.e.*, 1 month and 2 months after transplanting.

IRRIGATION

Endive is a shallow rooted crop so it prefers a uniform and frequent supply of water for its tender growth. Total 20–30 cm water is necessary, depending on seasonal variation, planting season and variety. Soil type does not affect the amount of total water needed but it affects the frequency of water application. Light soils require irrigation more frequently as compared to heavy soils. Depending on season and availability of soil moisture, irrigation is applied at an interval of 10–15 days. It is advisable not to irrigate the field too frequently; however, the care should always be taken that the field may not dry and become compact too much, otherwise the root development is affected adversely. An irregular supply of moisture may cause discolouration of young leaves margins. The plant is sensitive to waterlogging conditions.

HOEING AND WEEDING

Weeding and hoeing are done regularly throughout the summer to retain moisture and porosity. The endive field in early stage should be kept weed-free since in early stages, the plants may not compete with weeds due to poor growth. Thus, at least two shallow hoeing are beneficial and necessary to keep the weeds down and provide good soil environment to the roots for their development. One weeding and one earthing up during early stage of crop growth are necessary to promote root development. Another hoeing and earthing up are done before bolting to provide support to the seed plants.

BLANCHING

About a week before harvesting, the heads may be tied up in order to blanch them and to moderate their bitterness. Blanching can also be achieved by covering each plant with a pot or container to exclude light for about 10 days. There are self-blanching cultivars, especially when planted densely.

HARVESTING

Endive becomes ready for harvest in 60–100 days after planting. Harvesting can start when the heads have reached a marketable size (weighing 250–400 g). It is done by cutting the heads from the roots, removing the outer, discoloured or damaged leaves and placing the heads upside down in containers. Per crop per hectare, 200 quintals of marketable produce can be obtained.

POST-HARVEST MANAGEMENT

Endive can be retained fresh only for 1 day at ambient room temperature. However, the healthy heads can be stored for up to two weeks at 0–1° C temperature and 90–95% relative humidity. Endive when grown in the tropics, it often becomes very bitter in taste; however, this bitterness can be reduced by packing the individual head tightly in plastic foils and storing them for 4–5 days at 7° C temperature.

PEST MANAGEMENT

1. Aphids (*Myzus persicae, Nasonovia ribisnigri* and *Brachycaudus helichrysi*): Small soft-bodied insects on underside of the leaves and stems of plant are usually green or yellow in colour but may also be pink, brown, red or black, depending on species and host plant. If aphid infestation is heavy, it may cause the leaves yellow and distorted with necrotic spots on leaves. As a result, the growth becomes stunted. They secrete sticky sugary substance called honeydew, which encourages the growth of black sooty mould on the plants. Control measure include growing aphid-tolerant varieties. Use of reflective mulches such as silver coloured plastic to deter aphids from feeding on plants. Using insecticidal soaps or oils such as neem or canola oil to control the aphids.

2. Thrips (*Frankliniella occidentalis* and *Thrips tabaci*): Insect is small (1.5 mm) and slender and best viewed using a hand lens. Adult thrips are pale yellow to light brown and the nymphs are smaller and lighter in colour. If population is high, the leaves become distorted. Leaves covered in coarse stippling may appear silvery and leaves speckled with black faeces. The insect transmits viruses such as tomato spotted wilt virus. Avoid planting next to onion or garlic where very large population of thrips can build up. Use reflective mulches early in growing season to deter thrips. Blue sticky cards have been found to be the most attractive colour for trapping thrips. Spray Spinosad at 1–1.5 ml/l of water if thrips become problematic.

3. Leaf miner (*Liriomyza* spp.): Heavy mining by the insect can result in white blotches on leaves. As a result, they drop from the plant prematurely. Early infestation reduces yield. Adult leaf miner is a small black and yellow fly, which lays its eggs in the leaf. Larvae after hatching feed on leaf interior. Mature larvae drop from leaves into soil to pupate. The entire life cycle can take as little as 2 weeks in warm weather. The insect may go through 7–10 generations in a year. Plant seedlings free from damage. Remove plants from soil immediately after harvest. Spray the crop with selective insecticides, such as Spintor and Proclaim @t 2 ml/l of water.

4. Flea beetles (*Epitrix spp*. and *Phyllotreta spp*.): The pest responsible for damage is a small (1.5–3.0 mm) dark coloured beetle that jumps when disturbed. The beetles often shiny in look make small holes or pits in leaves that give the foliage a characteristic shot hole appearance. Young plants and seedlings are particularly susceptible. Plant becomes stunted. Severe infestation may kill the plant. Younger plants are more susceptible to flea beetle damage than older ones. During winter season, flea beetles survive on nearby weed species, in plant debris, or in the soil. The insects may go through a second or third generation in 1 year. Plant the crop early to allow establishment before the beetles become a problem. Grow cruciferous plants as a trap crop. Apply a thick layer of mulch, which may help in preventing the beetles reaching the surface. Spray Spinosad, Bifenthrin or Permethrin 2 ml/l of water. Spray the crop with Actara at 100–200 g/ha.

DISEASE MANAGEMENT

1. Damping-off (*Pythium spp*. and *Rhizoctonia solani*): The disease is most common in poorly drained soils having excessive moisture especially at bit high temperature. Densely sown nurseries are more prone to damping-off disease, which may be preemergence (seed decaying) and post-emergence (rotting of collar region due to the attack of fungi, leading to collapsing and death of seedlings). Sterilize the soil by drenching with 0.2% Captan solution. Collect seeds from disease-free plants. Sow the seeds shallow. Treat the seed with Captan at 2–3 g/kg of seed. Stop irrigating the nursery. Increase air circulation. Remove all the infected seedlings from the nursery.

2. Downy mildew (*Bremia lactucae*): The disease appears as light green to yellow angular spots on upper surface of the leaves, which are delineated by leaf veins. White fluffy growth of pathogen develops on underside of these spots. As the disease spreads, the upper side of the leaves may also show downy white fungus growth. With time, these lesions turn brown and dry

up. Older leaves close to the ground usually are attacked first. Severely infected leaves may die. Rarely, the pathogen can be systemic, causing dark discolouration of stem tissue. It may also cause losses in transit. The disease is favoured by cool rainy weather. Night temperature of 5–10°C and day temperature of 12–20°C with relative humidity of 98% are ideal for its development. As the temperature increases, the disease starts disappearing. Control measure include growing resistant varieties; applying irrigation in such a way that leaves surface may remain dry and spraying the crop with Dithiane M-45 at 0.2%.

Volume: 06 Issue No: 09

PALAK OR BEET SPINACH – AN UNDERUTILIZED NUTRITIOUS LEAFY VEGETABLE

Article ID: AG-VO6-I09-134

[1*]V. Krishnan, [1]V. Kanthaswamy, [1]M. S. Marichamy, [2]B. Bavithra, [3]S. Priyanga and [3]N. Bavya

[1]Faculty, [2]Ph. D. Scholar & [3]PG Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author: V. Krishnan

Introduction

Palak or Indian spinach, botanically called *Beta vulgaris* var. *bengalensis*, belonging to Chenopodiaceae family with 2n = 18. originates from Asia but is now grown in most tropical regions. Indian spinach is a leaf vegetable. It is usually cooked (like true spinach) but can also be used raw in salads. When cooked, Indian spinach looks and tastes similar to true spinach (*Spinacia oleracea*), which is probably why it got this name.

ORIGIN AND DISTRIBUTION

Spinach beet is most probably a native of Indo-Chinese region. It was known in China as early as 647 AD. Spinach beet, Swiss chard and Garden beet has a chromosome number 2n = 2x = 18, indicates their close relationship. Leaves of this crop might have been first used in Bengal and hence it is known as *Beta vulgaris* var. *bengalensis*

BOTANICAL DESCRIPTION

Beta vulgaris is an herbaceous biennial or, in rare cases, perennial plant that can grow to a height of 120 cm (rarely 200 cm); cultivated varieties are often biennial. The roots of the cultivated forms are brown, fibrous, occasionally bloated, and woody in the wild subspecies, or dark red, white, or yellow in the subspecies *vulgaris*.

The stems are simple or branching in the upper section, and their surface is corrugated and striate. In their wild forms, the stems are frequently procumbent. The petioles of the basal leaves are lengthy and may, in certain cultivars, be thickened and red, white, or yellow. The

simple leaf blade is whole or undulate, oblanceolate to heart-shaped, dark green to dark red, and slightly meaty. It typically has a noticeable midrib.



Inflorescences with dense, spike-like, and basally interrupted flowering are formed. The axils of short bracts or the upper portion of the inflorescence without bracts contain one to three (sometimes eight) flowered glomerules with tiny flowers. These hermaphrodite flowers, which are typically green, but may have a reddish hue, are shaped like urns. They are composed of five perianth segments (known as tepals) that are fused at the base, as well as five stamens and a partially inferior ovary containing 2-3 stigmas. The flowers can be pollinated by wind or insects, although wind pollination is more prevalent.

RELATED SPECIES

1. *Beta vulgaris* sub sp. *maritima*: Found as wild on seashores of Britain and throughout Europe and Asia to the East Indies.

***2. Beeta vulgaris* sub sp. *adenensis*:** Occurring in disturbed habitats and steppes of Southeast Europe (Greece) and Western Asia

3. *Beta vulgaris* sub sp. v*ulgaris:* This is commercial beet sugar cultivated in temperate regions of the world for sugar production.

CULTIVATED TYPES OF PALAK

On the basis of pigmentation of midrib and leaf veins, Spinach Beet or palak cultivars can be divided into two groups

1. **Redish midrib and leaf veins.**

2. **Green midrib and leaf veins.**



Redish midrib and leaf veins Palak



Green midrib and leaf veins Palak

COMMERCIAL VARIETIES

1. Punjab Green: This cultivar was developed by Punjab Agricultural University, Ludhiana, through selection. Its plants are semi-erect, foliage is shining dark-green, thick, long and broad. The leaves are succulent and free from sourness. There is mild purple pigment on the stem. It is ready for first cutting 30 days after sowing. Its average yield is 3 t/ha. It is slow bolter.

2. HS 23: This cultivar was developed by Haryana Agricultural University, Hissar, Haryana through selection. It produces dark-green, large, thick, tender and juicy leaves. It is a quick growing cultivar and is ready for first cutting 30 days after sowing. A total of 6-8 cuttings at two weeks interval can be obtained.

3. Ooty 1: It was developed at Horticultural Research Station, Ooty of Tamil Nadu Agricultural University through selection from Himachal Pradesh. Leaves are green with a length of 40-50cm and breadth of 8-10cm.

The crop comes to first harvest 45 days after sowing. Subsequent harvests can be done once in 15 days for 4 times. The yield is 1.5 tones/ha/cutting.

4. All Green: It was developed at the Indian Agricultural Research Institute, New Delhi. It produces green tender leaves and gives about 6-7 cuttings at 15-20 days interval.

It yields about 12 t/ha.

5. Pusa Harit: This cultivar was developed by hybridization between sugar beet and local palak at IARI Regional Station, Katrain, HP. It produces thick, green, very large and slightly crinkled leaves. It is a heavy yielder and has very late bolting habit as it has low chilling requirement.

6. Jobner Green: This was developed at Jobner campus of University of Udaipur by selection from a spontaneous mutation detected from a local collection SI. No. 5. It produces green, large, thick and tender leaves with strong flavour having entire margin. It is a high yielder and gives an average yield of 30 t/ha.

NUTRITIONAL VALUE

Fresh leaves contains 20-25 kcal, protein 2.5 g, carbohydrates 3.5 g, dietary fiber 2.5 g, fat 0.8 g, calcium 110 mg, iron 2.5 mg, magnesium 75 mg, potassium 550 mg, Vitamin C 27.5 mg, folate 190mcg, and suffiucient vitamin A and vitamin K. It is valued as a low-calorie, nutrient rich leafy vegetable, particularly for iron, calcium, potassium, folate, vitamin A, vitamin C and dietary fiber.

HEALTH BENEFITS

1. Blood improvement: It is rich in folate and iron that promotes normal red blood-cell production.

2. Good for digestive health: Its dietary fiber supports regular bowel movements and digestive health.

3. Bone health: It is rich in calcium and vitamin K to maintain health bones.

4. Eye sight improvement: It is rich in carotenoids and vitamin A that helps maintain normal vision.

5. Improves immunity: Its vitamin C and other antioxidants help to protect cells and support normal immune function.

6. Maintain blood pressure: Its potassium helps to maintain normal blood pressure.

7. Weight management: Its low calorie helps to be a part of weight reduction diet.

CLIMATE AND SOIL

Spinach beet is a winter season crop, it can be grown throughout the year. It can tolerate frost better than other vegetables. It can also tolerate warm weather but high temperature leads to premature bolting without giving economic yield**.** Palak can be grown on any type of soil possessing good fertility and drainage. Sandy-loam soil is most suitable for Palak. Although,

palak can tolerate slightly alkaline soil, high yields of better-quality greens are produced in neutral soils having a pH of 7.0.

SOWING AND SPACING

The main sowing season in plains is from last week of August to second week of November. In places with mild climate, it may grow throughout the year. In hilly regions, palak is sown from March-May. To improve germination, seeds are soaked in water overnight before sowing. Sowing can be done either by broadcast method or by line sowing. Line sowing is more desirable as it facilities weeding, hoeing and harvesting. Line spacing is maintained at 20cm and thinning is done to maintain plant spacing within lines at about 5cm. Seed rate varies with the crop season. For winter crop, use 10-15kg seed/ha and for summer crop 25-30kg/ha seed is required.

MANURES AND FERTILIZERS

Apply 25 tons of farmyard manure, along with 87.5kg N and 30kg P_20_5/ha. Apply whole of farmyard manure and P_2O_5 and half of N at the time of soil preparation. The remaining half N may be applied in two split doses, one after each cutting followed by a light irrigation.

IRRIGATION

In case of insufficient soil-moisture, apply first irrigation immediately after sowing. Subsequent irrigations may be given at an interval of 4-6 days during summer and 10-12 days during winter. However, rainy season crop does not require much irrigation.

INTERCULTURAL AND WEEDING

Hand weeding is still a common practice to control weed. Generally, 2-3 hoeing cum hand weeding are required to control weed. It also helps to loosen soil for proper aeration.

HARVESTING

The crop will be ready for harvesting in about 3-4 weeks after sowing Subsequent cuttings should be taken at an interval of 20-25 days depending upon variety and season. During summer, only one harvesting is recommended. Harvesting is not done early in the morning because there is dew on the crop. After harvesting it is washed, trimmed, graded and bunched before marketing.

Volume: 06 Issue No: 09

SPINACH AN UNDERUTILIZED SALAD AND LEAFY VEGETABLE

Article ID: AG-VO6-I09-135

[1]Bavithra B, [2*]V. Krishnan, [2]V. Kanthaswamy, [2]M. S. Marichamy, [3]S. Priyanga and [3]N. Bavya

[1]Ph. D. Scholar, [2]Faculty, & [3]PG Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author: V. Krishnan

Introduction

Spinach, botanically called Spinacia oleracea (2n = 12), belongs to the Amaranth family Amaranthaceae. Its leaves are a common edible vegetable consumed either fresh, or after storage using preservation techniques by canning, freezing, or dehydration. It may be eaten cooked or raw and the taste differs considerably; the high oxalate content may be reduced by steaming. The world production of Spinach is around 33 M tonnes. China produces 93% of world Spinach, followed by USA, Japan and Turkey. Fresh spinach is sold loose, bunched, or packaged fresh in bags.

ORIGIN AND DISTRIBUTION

Spinach originated in South west Asia. The closely related species *S. tetranda* is considered to be its ancestor, and other related species comprise *S. spinosa*, *S. inermis*, and *S. turkestanica*. *Spinacia oleracea* was probably brought in the 14th century by the Arabs to Spain, from where it spread to other countries by the 16th century (George 1985). It was cultivated in Spain in the eighth century and it was the Spaniards who brought it to the United States (Herbst 2001).

BOTANICAL DESCRIPTION

Spinach, *Spinacia oleracea*, is an annual plant. It grows to a height of up to 30 cm. The leaves are alternate, simple, and ovate to triangular, either flat or curled. The leaves are very

variable in size, from about 2-30 cm long and 1-15 cm broad, with larger leaves at the base of the plant and small leaves higher





Spinach –Male flower



Spinach –Female flower

on the flowering stem. The leaves are dark green that are simple, opposite or alternate, with margins that are entire or coarsely toothed and without stipules. The flowers are solitary or aggregated in cymes, spikes, or panicles and typically perfect (bisexual) and actinomorphic. The bracteate flowers are regular with 4-5 petals, often joined. The flowers are inconspicuous, yellow-green, 3-4 mm diameter. There are 1-5 stamens. The hypogynous ovary has 3-5 joined sepals. Fruit is a small hard dry lumpy fruit cluster 5-10 mm across containing several seeds.

FLORAL BIOLOGY

Usually spinach plants are dioecious *viz*.. male and female flowers are borne in separate plants. In male plants, two categories *viz*., extreme male and vegetative male are seen. Female plants are larger in size and remain in vegetative phase for longer period. Besides these, hermaphrodite plants are also found with bisexual flowers and a few male flowers also. Based on

the morphology of seeds, two distinct types are classified as smooth seeded type and prickly seeded type.

CULTIVATED TYPES OF SPINACH

There are three basic types of Spinach:

1. **Savoy Spinach:** This has dark green, crinkly and curly leaves. It is the type sold in fresh bunches in most supermarkets. One heirloom variety of savoy is Bloomsdale, which is somewhat resistant to bolting.

2. Flat/smooth leaf spinach: This has broad smooth leaves that are easier to clean than savoy. This type is often grown for canned and frozen spinach, as well as soups, baby foods and processed foods.

3. Semi-savoy Spinach: This is a hybrid variety with slightly crinkled leaves. It has the same



Savoy Spinach Flat or smooth leaf Spinach Semi- savoy Spinach

texture as savoy, but it is not as difficult to clean. It is grown for both fresh market and processing. "Five Star" is a widely grown variety and has good resistance to running up to seed.

NUTRITIONAL COMPOSITION

The spinach leaves contain 2.90 g of carbohydrates, 2.00 g of protein, 0.70 g of fat, 0.60 g of crude fibre, 1.70 g of mineral ash, 9300 IU of Vitamin A, 28 mg of Vitamin C and 658 mg of Oxalic acid. Cooking spinach significantly decreases its vitamin C concentration, as vitamin C is degraded by heating. Folate levels may also be decreased, as folate tends to leach into cooking liquid.

TOXICITY IN SPINACH

Spinach contains moderate amounts of iron and calcium, it also contains oxalates, which may inhibit absorption of calcium and iron in the stomach and small intestine. Cooked spinach has lower levels of oxalates, and its nutrients may be absorbed more completely. Spinach is rich in nitrates and nitrites, which may exceed safe levels if spinach is over-consumed

USES OF SPINACH

Spinach is used raw in salads and cooked. The leaves may also be canned or quick frozen. Spinach can be used as a source of vitamin A, B_1, B_2, niacin and calcium. The crop also has a hypoglycaemic effect that can be used in treating urinary calculi and lung inflammation. The seeds can be used as a laxative and for treating breathing difficulties and liver inflammation

CLIMATE AND SOIL

Spinach requires cool weather for optimal growth and may survive over winter in temperate regions. Spinach seeds germinate at 2-30° C. However, 7-24° C is optimum. Seeds will not germinate well in warm weather. Although spinach will grow in temperatures ranging from 5-24° C, growth is most rapid at 15-18° C. The plant requires a constant and uniform supply of water in order to obtain a good crop of high quality. During spinach production, the soil should never be allowed to dry out. Spinach grows well on a variety of soils, although fertile, sandy loams with a high organic matter content are preferred. Heavier soils can be quite productive if these are well drained and irrigated with care. Spinach is particularly sensitive to saturated soil conditions and to acidity. The optimum soil pH is 6.2 to 6.9.

COMMERCIAL VARIETIES

1. Avon: It is a semi-savoy type for early spring planting. It has large, slightly crinkled, dark green leaves and has resistance to blight and mildew (44 days to harvest).

2. Bloomsdale: Long Standing' spinach. It is an older variety and one of the best tastings but with no disease resistance. It grows erect, with thick, very crinkly, glossy dark green leaves. It is good for late spring and early summer harvest and will often overwinter with mulching. Other Bloomsdale types have been selected for earlier maturity and slow bolting (48 days to harvest).

3. Melody: It is an All-America Selection winner (1977) that has tender, dark green, lightly crinkled leaves with superior flavour. It has tolerance to downy mildew races 1 and 2 and is resistant to cucumber mosaic virus. It grows quickly to a large plant, so is good for spring or fall plantings. (42 days to harvest).

4. Regal: It is a semi-savoyed variety suited to dense plantings for baby leaves. It is resistant to downy mildew races 1-7. (30 days to harvest).

5. Olympia: It has smooth, dark green leaves. It is very fast-growing but is also very slow to bolt, so it is good for spring and early summer planting. It is resistant to downy mildew races 1, 2, and 3 (46 days to harvest).

6. Space: It is another smooth-leaved, bolt-resistant variety suitable for later plantings. It has a thick leaf that doesn't bruise as easily as some types, even when small. Good for both baby spinach and full-grown plants (39 days to harvest).

7. Tyee: It is a fast-growing savoy type with thick dark green leaves, similar to Melody. The upright growth habit helps produce cleaner leaves. It is very slow to bolt and is resistant to downy mildew races 1 and 3 (39 days to harvest).

8. Virginia savoy: It is a prickly seeded cultivar. It has blistered and large dark green leaves with round tip. Plants are vigorously growing and have an upright growth habit.

9. Early Smooth leaf: This is a smooth leaved cultivar with pointed tip. The seeds are smooth.

MANURES AND FERTILIZER

Preplant phosphorus (P) application ranges from 56-112 kg/ha. N quantities should range from 90-224 kg/ha, depending on the length of the growing season. Approximately 56 kg/ha of N is applied before planting, followed by one to three side dressings or water-run applications.

WEEDING AND IRRIGATION

Two hand-hoeing are necessary. Shallow cultivations are also used to control the weeds on spinach fields. A typical weed control programme includes the use of a preplant incorporated or a pre-emergent herbicide. The most effective and efficient control of weeds is by integrated weed management. Spinach fields are sprinkler irrigated to ensure the germination of the seed. The very first irrigation is performed immediately after planting, and a second one can follow just before emergence. The first irrigation will be needed to germinate the crop, but several short sprinkler applications are often necessary to prevent soil crusting. Once a uniform stand is established, most growers switch to furrow irrigation.

HARVESTING

Harvest begins the first week of June and continues until October. The crop should be harvested while the leaves are lush green and tender, which occurs before seed stalks harden and leaves yellow and become tough. The entire plant is usually harvested by cutting just above the

ground level when there are at least 5 to 6 leaves - usually 25 to 55 days after seeding within the growing season. Cutting should take place at the coolest time during the day and it is very important that the plants are dry during harvesting. After harvesting, spinach plants will require 10-14 days to produce leaves for a second crop. Average yield of spinach crop is about 50-60 quintals/ha in a crop duration of 75-90 days.

STORAGE

Spinach can be held 10 to 14 days at a temperature of 0^0 C and a relative humidity of 95-100%. Wilting, yellowing of leaves and decay are likely to occur after 10-14 days in storage. Spinach is very sensitive to ethylene and should not be stored or transported with apples, melons or tomatoes because accelerated yellowing with result.

PEST MANAGEMENT

1. Leaf miner: Spinach leaf miner is a fly that lays its eggs on the undersides of the leaves. The maggots burrow into the leaf and create conspicuous trails as they eat their way through the leaf. Remove the leaves with eggs or mines but don't spray chemicals since they are ineffective once the insect is inside the leaf. Put floating row cover on after thinning. Use supports, such as hoops, to keep the fabric off of the plants. Slugs can also be a problem in very moist situations. Do not mulch around the plants.

2. Aphids: Aphids may occasionally infest plants in some areas. Aphids can be controlled by removing infested leaves or with chemicals if numerous. Minor infestations are often destroyed by a variety of natural enemies, such as green lacewings, lady bird beetles and parasitic wasps. Aphids may also be washed off the leaves with a vigorous stream of water.

DISEASE MANAGEMENT

1. Seed borne fungi: Spinach is frequently the host of several parasitic fungi that endanger commercial plant production or seed production. Seed-borne fungi cause several diseases, such as leaf spot (*Cladosporium variabile* and *Phyllosticta spinaciae*), anthracnose (*Colletotrichum dematium f. spinaciae*), damping off (*Rhizoctonia solani* and *Verticillium dahliae*) and wilt (*Verticillium* sp.).

2. Soil borne fungi: Some soilborne fungi attack germinating seeds and prevent germination (*Pythium* sp., *Phytophthora* sp., *Phoma* sp.). Vegetative plants are susceptible to *Fusarium oxysporum* f. sp. *spinaciae*, *Peronospora jarinosa* and *P. spinaciae*.

3. Viral diseases: Serious diseases in spinach are caused by viruses, among which are identified: Cucumber mosaic virus (CMV), Turnip mosaic virus (TuMV), Tomato bushy stunt virus (TBSV), Spinach latent virus (SpLV), and Lettuce mosaic virus (LMV). Aphids are the vectors spreading virus diseases, but many viruses can be transmitted through seeds and pollen.

4. Leaf rust and Leaf spot: Spinach is susceptible to rust but most varieties are rust resistant. Occasionally leaf spots, either *Cercospora* leaf spot or Anthracnose, may develop on the upper sides of the leaves, then fall out to form holes. Fungicides will control these diseases. Choose resistant varieties if downy mildew is a problem in your garden.

Volume: 06 Issue No: 09

AGRITOURISM: A GAME CHANGER FOR FARMERS AND SUSTAINABLE RURAL DEVELOPMENT

Article ID: AG-VO6-I09-136

Balaji Parasuraman[1]*, Prahadeeswaran M[2], Rajkishore S K[3] and Jayasuriya S[4]

[1*]Professor, Department of Agricultural & Rural Management, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

[2]Associate Professor, Department of Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

[3]Assistant Professor, Department of Renewable Energy Engineering, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

[4]PG Scholar, Department of Agricultural & Rural Management, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

*Corresponding Author : Balaji Parasuraman

Abstract

Agritourism has emerged as a form of farm diversification that connects agricultural production with tourism, recreation, education, local food and rural experiences. Its development varies across countries according to farm structure, tourism demand, infrastructure, entrepreneurial capacity and institutional support. This review synthesizes literature on agritourism with emphasis on four dimensions: enterprise characteristics, economic performance, tourist preferences, and development requirements. Evidence from Europe, North America, Latin America, Africa and Asia is examined to identify common patterns and contextual differences. The literature indicates that agritourism can provide supplementary farm income and strengthen multifunctionality, although profitability is not automatic and depends on investment, resource allocation, visitor expenditure and managerial capabilities. Studies on tourist preferences consistently identify agricultural landscapes, natural environments, local food, farm participation, cultural experiences, recreation and hospitality as important components of the visitor experience, although their relative importance varies among market segments. The review

further indicates that infrastructure, finance, marketing, training, regulatory clarity and institutional coordination influence enterprise development. Overall, agritourism is best understood as a context-specific multifunctional farm enterprise rather than a uniform tourism product. Future development requires stronger integration of agricultural resources, visitor demand, enterprise economics and institutional support.

Keywords: Agritourism, Farm Diversification, Economic Performance, Tourist Preferences, Farm Tourism, Rural Development

1. Introduction

Agriculture and tourism are increasingly interconnected through forms of rural diversification that allow farms to provide tourism-related experiences in addition to producing agricultural commodities. Agritourism represents one of the most prominent forms of this integration, encompassing activities such as farm visits, agricultural demonstrations, recreation, direct sales, educational programmes, food experiences and farm-based accommodation. Chase *et al*. (2018) conceptualized agritourism around five broad components: education, direct sales, entertainment, outdoor recreation and hospitality. This broad framework illustrates that agritourism extends beyond accommodation and involves the conversion of agricultural resources into visitor experiences. A clear conceptual boundary is nevertheless important. Agritourism is often used interchangeably with farm tourism and rural tourism, although these terms do not necessarily describe identical activities. Phillip *et al*. (2010) proposed that agritourism can be differentiated according to whether tourism occurs on a working farm, the degree of visitor contact with agricultural activity and the authenticity of the agricultural experience. Streifeneder (2016) similarly emphasized the continuing importance of agricultural activity in distinguishing authentic agritourism from broader countryside tourism.

The growth of agritourism is closely associated with farm diversification and multifunctionality. Farmers may seek alternative or supplementary income sources in response to changing commodity markets, production costs and rural economic conditions. Agritourism can allow existing farm resources such as land, crops, livestock, farm buildings, landscapes and agricultural knowledge to generate additional economic value. Research from Italy, the United States, and Mexico demonstrates that agritourism can be part of broader farm diversification strategies, although the resulting economic benefits vary across enterprises and locations (Arru *et al*., 2019, 2021; Lucha *et al*., 2016; Pérez-Olmos & Aguilar-Rivera, 2021).

The demand side is equally important because agricultural resources become tourism products only when visitors perceive them as valuable experiences. Studies have identified landscapes, local food, farm participation, recreation, cultural experiences, education and hospitality as recurring components of agritourism demand (Gao *et al*., 2014; Liang *et al*., 2025; Sarath *et al*., 2022, 2023). Against this background, this review examines the literature through four interrelated objectives: to examine the operational characteristics of agritourism enterprises across different geographical contexts; to synthesize evidence concerning economic performance and profitability; to examine tourist preferences for different agritourism experiences; and to identify infrastructure, skills, institutional and policy conditions associated with agritourism development.

2. Review Approach and Scope

The study adopts a narrative and thematic review approach. Published empirical studies, conceptual papers, systematic reviews and scoping reviews concerning agritourism, farm diversification, economic performance, tourist preferences, sustainability and institutional development were examined. The literature was selected to provide geographical diversity, covering Europe, North America, Latin America, Africa and Asia, with particular attention to Italy, the United States, Mexico, Georgia, Zimbabwe, China and India. This geographical breadth is important because agritourism is strongly influenced by agricultural structure, tourism markets, cultural conditions and institutional arrangements.

The review synthesizes evidence around four broad dimensions: enterprise structure, economic performance, visitor preferences and development requirements. Because the reviewed studies differ substantially in objectives, samples, locations and analytical methods, a statistical meta-analysis was not attempted. Instead, the findings are compared thematically to identify recurring patterns, contextual differences and research gaps. Recent bibliometric and structured reviews also indicate that agritourism research has expanded considerably, yet remains fragmented across themes such as farm diversification, sustainability, entrepreneurship, tourism demand, and rural development (Rauniyar *et al*., 2020; Ammirato *et al*., 2020).

3. Agritourism: Concept, Evolution and Enterprise Characteristics

Agritourism has developed in different forms according to agricultural structure, tourism markets and available farm resources. At the enterprise level, it may range from short farm visits and direct sales to educational programmes, recreational activities, food services and overnight

accommodation. Phillip *et al*. (2010) demonstrated the diversity of agritourism through a typology based on working-farm status, visitor contact and authenticity. Flanigan *et al*. (2014) subsequently incorporated both provider and visitor perspectives, illustrating that agritourism products differ substantially, such as interaction between farms and visitors.

European experience provides some of the longest-established examples. Farm tourism in Europe has developed through varying combinations of accommodation, agricultural production, food and recreational activities. Potočnik-Slavič and Schmitz (2013) noted substantial differences in farm tourism development across European regions, reflecting differences in agricultural structures, rural economies and tourism conditions. Italian research particularly emphasizes multifunctionality. Arru *et al*. (2019) examined the technical efficiency of agritourism and recreational services in Sardinia and argued that the coexistence of agricultural and tourism activities can create opportunities for better utilization of farm resources. However, the benefits depend on the efficient allocation of resources among different activities.

Research from the United States similarly demonstrates that agritourism enterprises vary according to farm size, labour, years in operation and business characteristics. Barbieri and Mshenga (2008) found that farm acreage, number of employees and years in business were positively associated with gross agritourism sales. Tew and Barbieri (2012) further showed that providers pursue both economic and non-economic objectives, including acquiring new customers, educating the public about agriculture and improving family quality of life. In Mexico, agritourism has been associated with agricultural multifunctionality and diversification, although Pérez-Olmos and Aguilar-Rivera (2021) found that research and public support remained comparatively limited. In Zimbabwe, research has similarly shown that farms possess agricultural and natural resources suitable for tourism, while the extent of tourism diversification and hospitality provision varies considerably between enterprises (Baipai *et al*., 2023, 2024).

The Indian literature reflects similar diversity. Sinha and Ali (2024) identified farm stays, farm-based activities, rural accommodation and agricultural experiences among the principal forms of agritourism in India. Recent supply-side research in Tamil Nadu has also highlighted variation in farmer motivations, enterprise characteristics and development constraints (Sennimalai *et al*., 2025).

The evidence therefore indicates that agritourism should not be treated as a homogeneous enterprise category.

Table 1. International evidence on agritourism enterprise characteristics

Country/region	Major focus	Common components	Key observation
Italy	Farm diversification and efficiency	Accommodation, food, recreation and direct sales	Benefits depend on efficient resource allocation
United States	Enterprise performance and provider objectives	Farm visits, recreation, education and direct sales	Farm and owner characteristics influence performance
Mexico	Multifunctionality and rural development	Farm experiences and local products	Agritourism remains relatively underdeveloped
Europe	Farm tourism development	Farm stays, food and recreation	Development differs across regions
Zimbabwe	Sustainable agritourism	Farm tours, nature and animal experiences	Agricultural resources are available but tourism diversification varies
China	Rural tourism demand	Landscape, food, culture and recreation	Visitor preferences differ among segments
India	Agritourism development	Farm activities, food, accommodation and recreation	Development is heterogeneous across regions

Source: Synthesis of 11 reviewed studies

Its structure depends on agricultural resources, investment, visitor markets, location, accessibility and the degree of integration between agriculture and tourism.

4. Agritourism as a Farm Diversification and Economic Activity

The economic rationale for agritourism is closely related to farm diversification. Agricultural land, buildings, livestock, crops, farm landscapes and knowledge can generate value not only through commodity production but also through tourism experiences. This multifunctional use of farm resources can create supplementary revenue streams and potentially reduce reliance on agricultural commodity markets. However, diversification does not automatically lead to profitability. Tourism activities introduce additional costs for labour, infrastructure, food, maintenance, marketing, visitor safety and administration. Consequently,

economic performance depends on the balance between additional revenue and the resources required to generate it.

Arru *et al*. (2019) found that the coexistence of agricultural and recreational functions can generate efficiency benefits when farm resources are appropriately allocated. Their later analysis of 15 agritourism farms in Sardinia, however, demonstrated that economic outcomes remain heterogeneous and that agritourism does not automatically provide adequate remuneration for farm labour or guarantee profitability. Evidence from the United States provides a broader statistical perspective. Lucha *et al*. (2016), using data from more than 500 agritourism operations in Virginia, found that profitability was associated with characteristics including operation size, the share of income derived from agritourism and visitor expenditure. Access to capital was also relevant to economic outcomes.

Barbieri and Mshenga (2008) similarly found positive relationships between gross agritourism sales and farm acreage, employee numbers and years in business. These findings indicate that enterprise scale and accumulated operational experience can influence the capacity to generate tourism revenue. Provider motivations are also broader than income alone. Tew and Barbieri (2012) found that agritourism providers in Missouri viewed the activity as a means of attracting new farm customers, educating the public about agriculture and improving family quality of life. This indicates that economic performance should be considered alongside other outcomes when examining farm diversification.

The literature suggests that economic performance should consequently be assessed through several indicators. Revenue indicates the scale of tourism activity, while net returns account for the associated costs. Profit margins indicate the relationship between income and expenditure, whereas return on investment and benefit–cost ratios relate outcomes to capital requirements. Visitor numbers and occupancy can provide information on market demand, but they do not independently demonstrate profitability.

Table 2. Major dimensions for assessing economic performance of agritourism enterprises

Dimension	Representative indicators	Importance
Investment	Buildings, accommodation, equipment and site development	Indicates capital requirements
Operating cost	Labour, food, utilities, maintenance and	Measures the cost burden

	marketing	
Revenue	Accommodation, food, activities, admission and product sales	Measures income generation
Profitability	Gross return, net return and profit margin	Indicates financial outcome
Investment efficiency	ROI, B:C ratio and payback period	Relates returns to investment
Market performance	Visitor numbers, occupancy and visitor expenditure	Reflects demand and revenue potential
Diversification	Number and type of revenue streams	Indicates income diversification

Source: Synthesis based on Arru et al. (2019, 2021), Barbieri and Mshenga (2008), Lucha et al. (2016)

The literature therefore supports a multidimensional assessment of economic performance. Agritourism should be viewed as a potential diversification strategy whose economic value depends on the relationship between farm resources, investment, market demand and operating efficiency.

5. Tourist Preferences and the Agritourism Experience

The success of agritourism depends not only on the resources available on farms but also on visitor perceptions of those resources. Tourist preference research therefore provides an important demand-side perspective. Agricultural landscapes are consistently identified as important elements of the agritourism experience. Gao *et al*. (2014), examining potential and current agritourists in Missouri, Pennsylvania and Texas, found that respondents generally preferred natural and cultural landscape features, with wildlife, water resources, historic elements and farm animals among the attractive features. Their findings also indicated differences in preferences according to gender, previous agritourism experience and agricultural attachment.

Evidence from Italy further demonstrates that landscape quality can influence tourism demand. Torquati *et al*. (2017) used a choice experiment with agritourists in Umbria and found that preservation of traditional rural landscapes had a substantial influence on willingness to pay for an agritourism stay. The study also identified environmental protection, historical proximity and other site characteristics as relevant to visitor choice. Research in Tamil Nadu provides comparable evidence. Sarath *et al*. (2022) found that customers preferred natural features

followed by agricultural and cultural features in the agritourism settings studied in Coimbatore. Their analysis also indicated differences across customer segments based on income, family size, frequency of visits and agricultural linkages.

Sarath *et al*. (2023) subsequently identified five dimensions of customer preference in Tamil Nadu: farm landscape, farm activities, farm attractions, farm services and experience. The findings indicate that visitors value not merely the presence of agricultural land but the combination of activities, services and experiential elements associated with it. Recent research from China further supports the multidimensional nature of rural tourism demand. Liang *et al*. (2025) found positive preferences for natural scenery, local cuisine, cultural experiences, outdoor activities and accommodation, while higher prices and longer travel distances reduced preference. The study also identified distinct visitor segments, demonstrating that tourism markets should not be treated as homogeneous.

Taken together, these studies indicate that visitors evaluate agritourism as an integrated experience. The agricultural landscape provides the setting, while activities, food, culture, recreation and hospitality contribute to the experiential value. Consequently, visitor numbers alone provide limited information about demand quality; understanding what visitors value and how much they are willing to spend can provide greater insight into market potential.

6. Agricultural Landscape, Food, Culture and Authenticity

Agricultural landscapes are among the principal resources distinguishing agritourism from conventional tourism. Orchards, plantations, crop fields, livestock farms, traditional farm structures and rural ecosystems can become attractions when they are integrated into visitor experiences. The importance of landscape has been demonstrated across several contexts. Gao *et al*. (2014) reported strong preferences for natural and cultural landscape features, while Torquati *et al*. (2017) demonstrated the economic value that visitors placed on well-preserved traditional rural landscapes. Tamil Nadu research has similarly identified natural, agricultural and cultural features as important components of customer preferences (Sarath *et al*., 2022).

Food creates another direct connection between agriculture and tourism. Farm-produced and locally prepared foods can provide visitors with an opportunity to connect agricultural production with local consumption. Local cuisine can also communicate regional identity and cultural heritage. The importance of local food in rural tourism preferences is supported by

evidence from China, where local cuisine was among the positively valued attributes (Liang *et al*., 2025).

Cultural experiences similarly extend the value of the agricultural setting. Traditional farming practices, local knowledge, festivals, crafts and rural lifestyles can provide visitors with experiences that cannot easily be replicated in urban tourism environments. Authenticity is particularly relevant. Phillip *et al*. (2010) identified the working-farm context, visitor contact and authenticity as important dimensions for defining agritourism. Streifeneder (2016) similarly argued that agriculture should remain central when distinguishing authentic agritourism from broader countryside tourism.

Authenticity, however, does not imply the absence of visitor facilities. Accommodation, sanitation, food services, signage and visitor safety can improve accessibility and service quality. The central issue is whether these facilities support or replace the agricultural character of the experience. Thus, the tourism value of a farm arises from the interaction between agricultural resources and visitor-oriented services. Landscape, food, culture and participation become tourism assets when they are organized into meaningful and accessible experiences.

7. Sustainability, Rural Development and Local Economic Linkages

Agritourism is frequently associated with sustainable rural development because it can potentially generate economic, social and environmental benefits. Nevertheless, sustainability should not be assumed simply because tourism takes place in an agricultural environment. Economically, agritourism can diversify farm income, create employment and support value addition. Pérez-Olmos and Aguilar-Rivera (2021) identified agritourism as an element of agricultural multifunctionality and diversification in Mexico, although their review also highlighted limited research and insufficient public support.

Social benefits can emerge through interaction between farmers and visitors, cultural exchange, employment and preservation of rural knowledge. Agritourism may also generate local linkages when farms purchase products and services from surrounding communities. Environmental considerations are equally important because the agricultural landscape is itself a tourism resource. Poorly managed construction, waste, water consumption or visitor movement can reduce the quality of the environment that attracts tourists. Conversely, tourism income can potentially provide incentives for landscape maintenance and conservation.

Ammirato *et al*. (2020), through a systematic literature review, emphasized the relationship between agritourism and the economic, social and environmental dimensions of sustainability. Their review showed that sustainability research in agritourism has expanded beyond income generation to include rural development, environmental protection and community-related dimensions. Research in Zimbabwe illustrates the importance of resource-based sustainability. Baipai *et al*. (2024) found that agricultural farms possessed crops, livestock and natural resources that could support tourism but that hospitality and direct-sales functions were unevenly developed. The study emphasized better utilization of existing agricultural resources rather than simply expanding tourism infrastructure.

The sustainability literature therefore supports a balanced perspective. Agritourism can contribute to rural development, but its benefits depend on resource management, community linkages and the compatibility between tourism activities and agricultural production.

8. Infrastructure, Marketing, Skills and Institutional Requirements

The conversion of agricultural resources into tourism experiences requires appropriate infrastructure. Basic facilities such as sanitation, visitor access, parking, resting areas, signage, food services and safety arrangements influence the visitor experience. Accommodation-based enterprises require additional investment in rooms, housekeeping, sanitation, food preparation and maintenance. Infrastructure requirements differ according to enterprise type. A day-visit educational farm does not necessarily require the same level of investment as a farm providing overnight accommodation and full hospitality services. Investment therefore needs to be proportional to market demand and enterprise capacity.

Financial access is another important requirement. Lucha *et al*. (2016) identified access to capital as a factor associated with agritourism profitability, demonstrating the importance of investment capacity in enterprise development. Marketing is equally important because agritourism is primarily an experience-based product. Potential visitors need information concerning location, activities, food, accommodation, prices and facilities before deciding to visit. Digital platforms can increase visibility and allow farms to communicate directly with potential customers. However, marketing effectiveness should not be judged only by visitor numbers because the economic value of visitors also depends on expenditure and service costs.

Human resource capability is another important consideration. Farmers possess agricultural knowledge, but agritourism also requires skills in hospitality, communication,

customer service, digital marketing, financial management and visitor safety. Tew and Barbieri (2012) demonstrated that agritourism providers pursue a range of business and family objectives, while recent Indian research has highlighted the importance of entrepreneurial and hospitality-related characteristics in enterprise performance. Institutional support is particularly important because agritourism combines agricultural and tourism functions. Enterprises may interact with regulations relating to land use, accommodation, food safety, tourism registration, environmental management and public infrastructure. Lack of coordination can therefore increase the complexity of enterprise development.

Dsouza *et al*. (2024) reviewed Indian policy and regulatory frameworks and identified the need for strategic and financial support, together with implementation and monitoring through appropriate institutional mechanisms. Their review included 23 documents and demonstrated considerable variation in the extent to which state and union-territory tourism policies address agritourism. Recent supply-side research from Tamil Nadu has also emphasized the importance of understanding farmer motivations and the constraints affecting agritourism development (Sennimalai *et al*., 2025).

Table 3. Enterprise-level and institutional requirements for agritourism development

Enterprise-level requirements	Institutional-level requirements
Visitor access and sanitation	Clear regulatory framework
Accommodation and food facilities where appropriate	Financial and credit support
Visitor safety and interpretation	Training and capacity building
Digital and conventional marketing	Institutional coordination
Customer service and hospitality	Marketing and destination networks
Financial and operational management	Infrastructure development
Appropriate visitor activities	Monitoring and implementation
Waste and environmental management	Technical and extension support

Source: Synthesis of 8 reviewed literature.

The evidence consequently indicates that agritourism development depends on both farm-level capacity and the wider institutional environment. Attractive agricultural resources alone are insufficient if enterprises lack infrastructure, market access, finance, skills and regulatory support.

9. Comparative Synthesis and Research Gaps

The reviewed literature indicates that four relationships are particularly important in understanding agritourism. First, enterprise structure influences economic performance. Different forms of agritourism have different investment requirements, cost structures and revenue opportunities. Consequently, financial performance should be compared only after considering the characteristics of the enterprise. Evidence from Italy and the United States demonstrates that resource allocation, farm size, labour, visitor expenditure and business characteristics can influence economic outcomes (Arru *et al*., 2019, 2021; Barbieri & Mshenga, 2008; Lucha *et al*., 2016).

Second, visitor preferences influence product development. Landscape, local food, agricultural participation, recreation, culture and accommodation appear repeatedly across preference studies, but their relative importance differs among visitor groups and locations. Evidence from the United States, Italy, China and Tamil Nadu demonstrates that visitor preferences are context-dependent (Gao *et al*., 2014; Liang *et al*., 2025; Sarath *et al*., 2022, 2023; Torquati *et al*., 2017).

Third, enterprise capabilities influence the conversion of resources into experiences. Infrastructure, hospitality, marketing, communication and managerial capabilities determine whether agricultural resources can be effectively transformed into tourism products. The literature from Zimbabwe and India illustrates that agricultural resources may exist even when tourism diversification and supporting infrastructure remain limited (Baipai *et al*., 2024; Sennimalai *et al*., 2025).

Fourth, institutional conditions influence enterprise development. Finance, regulation, training, infrastructure and institutional coordination can either support or constrain farm-level diversification. The Indian policy literature particularly demonstrates the importance of strategic support and implementation mechanisms (Dsouza *et al*., 2024).

Several gaps remain. Much of the literature examines economic performance, visitor preferences or policy independently, while fewer studies integrate these dimensions. Economic studies also use different performance indicators, limiting comparison between enterprises and countries. Visitor studies demonstrate considerable market heterogeneity, but further work is required to connect visitor segments with spending behaviour and specific agritourism products. Developing-country contexts remain comparatively less represented in the international

literature, and institutional barriers require stronger integration with enterprise-level evidence.

A further gap concerns the relationship between agricultural authenticity and tourism commercialization. Increasing visitor facilities may improve comfort and revenue potential, but excessive commercialization could weaken the agricultural character that differentiates agritourism. Future research should therefore consider not only whether tourism activities generate economic returns but also how agricultural identity, visitor experience and resource conservation are maintained.

Overall, the literature supports a multidimensional understanding of agritourism in which agricultural resources, enterprise economics, visitor demand and institutional conditions interact. This provides a more useful basis for understanding agritourism than treating it simply as a rural accommodation or recreational activity.

10. Future Research Directions

Future research on agritourism should move beyond fragmented studies of individual enterprises and develop integrated frameworks linking agriculture, tourism, rural development and sustainability. Comparative studies across countries and rural regions are needed to identify the differences in farm structure, tourism markets, infrastructure and institutional environments shape agritourism development. Longitudinal research could examine how enterprises evolve from initial investment to operational maturity and assess their long-term economic, social and environmental outcomes. Greater attention is also required to emerging areas such as digital agritourism, climate resilience, smart tourism technologies, community participation and local value-chain development.

Visitor research could increasingly examine market segmentation, willingness to pay, repeat visitation and changing expectations for authentic agricultural experiences. Environmental research should assess water use, waste management, biodiversity and landscape conservation alongside economic outcomes. Future studies should also examine the effectiveness of government policies, financial mechanisms, training programmes and institutional coordination in supporting small and medium-sized farm enterprises. Methodologically, mixed-method, longitudinal, spatial, experimental and comparative approaches can strengthen the evidence base. Recent bibliometric research similarly highlights geographical concentration and the need for greater attention to digital innovation, climate change, governance and under-researched sustainability dimensions.

Conclusion

Agritourism has developed internationally as a multifunctional activity that connects agricultural production with tourism, recreation, education, food and hospitality. The literature demonstrates considerable variation in enterprise structure, ranging from short farm visits and direct sales to educational farms, recreational enterprises and accommodation-based operations. Studies from Italy, the United States and India demonstrate that economic performance varies among enterprises and should therefore be evaluated through multiple financial and market indicators. Tourist preference research demonstrates that agritourism demand is multidimensional. Agricultural and natural landscapes, farm participation, local food, cultural experiences, recreation, accommodation and hospitality contribute to visitor value.

Agricultural authenticity also remains central to the concept. The tourism experience gains much of its distinctiveness from actual agricultural production and rural landscapes. Infrastructure and hospitality can enhance accessibility and comfort, but they need to complement rather than replace the agricultural foundation of the enterprise. Finally, enterprise development is influenced by infrastructure, finance, marketing, training, regulation and institutional coordination. The Indian policy literature particularly demonstrates the need for clearer strategic and financial support and stronger implementation mechanisms.

References

Ammirato, S., Felicetti, A. M., Raso, C., Pansera, B. A., & Violi, A. (2020). Agritourism and sustainability: What we can learn from a systematic literature review. *Sustainability, 12*(22), 9575. https://doi.org/10.3390/su12229575

Arru, B., Furesi, R., Madau, F. A., & Pulina, P. (2019). Recreational services provision and farm diversification: A technical efficiency analysis on Italian agritourism. *Agriculture, 9*(2), 42. https://doi.org/10.3390/agriculture9020042

Arru, B., Furesi, R., Madau, F. A., & Pulina, P. (2021). Economic performance of agritourism: An analysis of farms located in a less favoured area in Italy. *Agricultural and Food Economics, 9*, 27. https://doi.org/10.1186/s40100-021-00199-z

Baipai, R., Chikuta, O., Gandiwa, E., & Mutanga, C. N. (2023). A framework for sustainable agritourism development in Zimbabwe. *Cogent Social Sciences, 9*(1), 2201025. https://doi.org/10.1080/23311886.2023.2201025

Baipai, R., Chikuta, O., Gandiwa, E., & Mutanga, C. N. (2024). An assessment of the extent to which agricultural farms meet the requirements for sustainable agritourism in Zimbabwe. *Cogent Social Sciences, 10*(1), 2347015. https://doi.org/10.1080/23311886.2024.2347015

Barbieri, C., & Mshenga, P. M. (2008). The role of the firm and owner characteristics on the performance of agritourism farms. *Sociologia Ruralis, 48*(2), 166–183. https://doi.org/10.1111/j.1467-9523.2008.00450.x

Chase, L. C., Stewart, M., Schilling, B., Smith, B., & Walk, M. (2018). Agritourism: Toward a conceptual framework for industry analysis. *Journal of Agriculture, Food Systems, and Community Development, 8*(1), 13–19. https://doi.org/10.5304/jafscd.2018.081.016

Dsouza, K. J., Shetty, A., Damodar, P., Dogra, J., & Gudi, N. (2024). Policy and regulatory frameworks for agritourism development in India: A scoping review. *Cogent Social Sciences, 10*(1), 2283922. https://doi.org/10.1080/23311886.2023.2283922

Flanigan, S., Blackstock, K., & Hunter, C. (2014). Agritourism from the perspective of providers and visitors: A typology-based study. *Tourism Management, 40*, 394–405. https://doi.org/10.1016/j.tourman.2013.07.004

Gao, J., Barbieri, C., & Valdivia, C. (2014). Agricultural landscape preferences: Implications for agritourism development. *Journal of Travel Research, 53*(3), 366–379. https://doi.org/10.1177/0047287513496471

Liang, Y., Chen, R., Xu, Y., Chen, X., & Zeng, Y. (2025). Segmenting Chinese rural tourist preferences: Insights from a choice experiment. *Humanities and Social Sciences Communications, 12*, 1588. https://doi.org/10.1057/s41599-025-05922-5

Lucha, C., Ferreira, G., Walker, M., & Groover, G. (2016). Profitability of Virginia's agritourism industry: A regression analysis. *Agricultural and Resource Economics Review, 45*(1), 173–207. https://doi.org/10.1017/age.2016.12

Pérez-Olmos, K. N., & Aguilar-Rivera, N. (2021). Agritourism and sustainable local development in Mexico: A systematic review. *Environment, Development and Sustainability, 23*, 17180–17200. https://doi.org/10.1007/s10668-021-01413-0

Phillip, S., Hunter, C., & Blackstock, K. (2010). A typology for defining agritourism. *Tourism Management, 31*(6), 754–758. https://doi.org/10.1016/j.tourman.2009.08.001

Potočnik-Slavič, I., & Schmitz, S. (2013). Farm tourism across Europe. *European Countryside, 5*(4), 265–274. https://doi.org/10.2478/euco-2013-0017

Rauniyar, S., Awasthi, M. K., Kapoor, S., & Mishra, A. K. (2020). Agritourism: Structured literature review and bibliometric analysis. *Tourism Recreation Research*. https://doi.org/10.1080/02508281.2020.1753913

Sarath, S., Sivakumar, S. D., Palanichamy, N. V., Suresh Kumar, D., & Somasundaram, E. (2022). A study on customers preferences towards landscape features of agri-tourism in Tamil Nadu. *Asian Journal of Agricultural Extension, Economics & Sociology, 40*(8), 86–95. https://doi.org/10.9734/ajaees/2022/v40i830940

Sarath, S., Sivakumar, S. D., & Chandrasekar, V. (2023). Developing agri-tourism based on customer's preferences in Tamil Nadu. In *Digital Economy Post COVID-19 Era* (pp. 425–438). Springer. https://doi.org/10.1007/978-981-99-0197-5_27

Sennimalai, S., Rao, B. V., & Sivakumar, S. D. (2025). Exploring the supply side dynamics of agritourism in Tamil Nadu. *Frontiers in Sustainable Tourism, 4*, 1498749. https://doi.org/10.3389/frsut.2025.1498749

Sinha, S., & Ali, M. H. (2024). Rise of agritourism in India: A scoping review. *Asian Journal of Agricultural Extension, Economics & Sociology, 42*(9), 58–68. https://doi.org/10.9734/ajaees/2024/v42i92541

Streifeneder, T. (2016). Agriculture first: Assessing European policies and scientific typologies to define authentic agritourism and differentiate it from countryside tourism. *Tourism Management Perspectives, 20*, 251–264. https://doi.org/10.1016/j.tmp.2016.10.003

Tew, C., & Barbieri, C. (2012). The perceived benefits of agritourism: The provider's perspective. *Tourism Management, 33*(1), 215–224. https://doi.org/10.1016/j.tourman.2011.02.005

Torquati, B., Tempesta, T., Vecchiato, D., Venanzi, S., & Paffarini, C. (2017). The value of traditional rural landscape and nature protected areas in tourism demand: A study on agritourists' preferences. *Landscape Online, 53*, 1–20. https://doi.org/10.3097/LO.201753

Vasadze, M. (2020). The role of agritourism in sustainable rural development of Georgia. *China-USA Business Review, 19*(5), 141–147.

Volume: 06 Issue No: 09

NATURE'S LITTLE BODYGUARDS: HOW WORMS AND MOTHS KEEP NANO-FARMING SAFE

Article ID: AG-VO6-I09-137

[1] Akshaya S, [2]R. Vinoth and [3]J. Gokulakrishnan

[1]B.Sc. (Hons) Agriculture**,** Institute of Agriculture (IOA), Tamil Nadu Agricultural University, Kumulur, Trichy, Tamil Nadu, India

[2]Teaching Assistant (PBG), Institute of Agriculture (IOA), Tamil Nadu Agricultural University, Kumulur, Trichy, Tamil Nadu, India

[3]Associate Professor (PBG), Institute of Agriculture (IOA), Tamil Nadu Agricultural University, Kumulur, Trichy, Tamil Nadu, India

*Corresponding Author : Akshaya S

Abstract

Nanotechnology offers vast potential across medicine and industry, yet ensuring the safety of engineered nanomaterials remains a critical challenge. Evaluating these tiny particles traditionally relies on simple cell cultures, which lack biological complexity, or mammalian models, which carry high costs and ethical concerns. This article explores how two non-mammalian organisms—the roundworm Caenorhabditis elegans and the greater wax moth larva Galleria mellonella—serve as effective bridging models in nanotoxicology. C. elegans provides a rapid, cost-effective platform for tracking physiological and behavioral changes, while its well-mapped genetics help uncover cellular stress and genetic damage. Complementing this, G. mellonella features an innate immune system surprisingly similar to mammals, making it ideal for detecting immune responses triggered by materials like carbon nanotubes and metal nanoparticles. Together, these alternative models streamline safety testing, support ethical research under the 3Rs framework (Replacement, Reduction, Refinement), and help ensure that technological innovation aligns with broader human and environmental health goals.

Keywords: Nanotoxicology, Nanosafety, *Caenorhabditis elegans*, *Galleria mellonella*, Alternative models, Immunotoxicity, 3Rs principles, High-throughput screening

Introduction

The Convergence of Nanotechnology and Agriculture: Nanotechnology is transforming modern agriculture. From nano-fertilizers and nano-pesticides to advanced soil conditioners, engineered nanoparticles (ENPs) offer targeted delivery and higher efficiency. However, their widespread environmental release makes them emerging contaminants.

When these nanomaterials enter the soil ecosystem, they interact with microscopic biological systems in complex ways. Understanding this "nano-bio interaction" is critical to ensure that technological progress does not come at the expense of soil health, crop quality, and long-term ecosystem balance.Engineered nanomaterials (NMs) are rapidly entering agriculture and medicine—powering smart nano-pesticides, targeted nano-fertilizers, and advanced drug delivery systems. However, as these synthetic particles enter living systems, their interactions with biological tissues (nano-bio interactions) remain complex and incompletely understood.

Standard cell-culture (in vitro) lab models are often inadequate for assessing toxicity. A single layer of cells in a dish cannot distinguish between normal, healthy immune defense and severe, dangerous immunotoxicity.



Caenorhabditis elegans



Caenorhabditis elegans

Instead of relying on costly and time-consuming mammalian testing, agricultural scientists use the free-living soil nematode *Caenorhabditis elegans* as a living biosensor.

To safely evaluate nanomaterial risks without relying on mammalian testing, researchers use the greater wax moth larva, *Galleria mellonella*.

This organism acts as a bridging model in Nanotoxicology.

1. **Caenorhabditis elegans (The Soil Nematode)**

1. The Space Travel & Microgravity Pioneer

C. elegans was one of the first multi-cellular organisms to be sent into space for biological research.

In 2003, thousands of C. elegans survived the catastrophic re-entry of the Space Shuttle Columbia (STS-107) inside protective aluminum canisters, demonstrating incredible cellular resilience under extreme pressure and temperature shifts.

Scientists currently use C. elegans on the International Space Station (ISS) to study muscle atrophy and how nanoparticle absorption changes in zero gravity.

2. Exactly 959 Cells with Fixed Lineage

Every single hermaphrodite C. elegans adult possesses exactly 959 somatic cell nuclei—no more, no less.

Scientists have mapped the entire cell division lineage from a single fertilized egg to all 959 cells. Because of this structural predictability, researchers can pinpoint precisely which individual cell (e.g., neuron #32 or gut cell #12) is damaged when exposed to specific engineered nanoparticles.

3. The Only Completely Mapped Brain

C. elegans possesses a nervous system of exactly 302 neurons, forming around 7,000 connections (synapses).

It remains the only organism on Earth with its entire neuronal connectome (brain circuit map) completely sequenced. This allows nanomedicine researchers to track exactly how nanoparticles disrupt sensory memory and motor coordination at a single-synapse level.

Why *Caenorhabditis elegans* is the Ideal Sentinel

1.Transparent Body - Direct visualization of nanoparticles inside tissues using fluorescence.

2.Rapid Life Cycle-3-day development allows multi-generational toxicity testing.

3.Genetic Conservation-Shares 60–80% of human/animal gene pathways for broad safety insights.

4.Ethical Compliance-Aligns with 3R Principles (Replacement, Reduction, Refinement).

Key Indicators of Nanoparticle Toxicity

Scientists observe several biological "endpoints" in C. elegans to measure nanoparticle impact:

Nanoparticle Exposure

- ├──► 1. Survival Rate (Lethality vs. Paralysis)
- ├──► 2. Growth Delays (Stunted Body Length)
- ├──► 3. Reproductive Decline (Reduced Brood Size)
- └──► 4. Behavioral Deficits (Slower Locomotion)

1.Survival vs. Paralysis

Evaluating survival rates establishes dose-response relationships. Researchers carefully distinguish actual mortality from temporary paralysis (where internal organ activity continues) to avoid overestimating chemical toxicity.

2.Growth and Development

Nanoparticles like Silver (AgNPs) impair nutrient absorption and stress-response pathways, delaying larval growth and reducing overall adult body length.

3.Reproductive Health

Reproduction is the most sensitive toxicity marker. Exposure to nanomaterials such as Zinc Oxide (ZnO) or Graphene Oxide (GO) damages reproductive tissues, drastically reducing egg production and brood size across successive generations.

4.Behavioral & Neurological Changes

Nanoparticles disturb the nervous system, impairing movement. Key indicators include:

Crawling & Reversals: Reduced speed and loss of motor coordination caused by graphene or quantum dot exposure.

Feeding Activity: Slower pharyngeal pumping rates leading to reduced food intake and altered fat distribution.

What Happens Inside the Nematode Cell?

- At the cellular level, nanoparticle toxicity is primarily driven by Reactive Oxygen Species (ROS), which cause oxidative stress.
- DNA Damage & Repair: Nanoparticles trigger double-strand DNA breaks. If repair pathways fail, programmed cell death (apoptosis) is initiated.
- Epigenetic Regulation: MicroRNAs (like mir-259 and mir-355) act as protective switches that help nematodes adapt to oxidative stress.

REALISTIC SOIL EXPOSURE MEDIA

- Liquid Media ----Particles aggregate easily; lower accuracy.
- Simulated Soil Water ----Low ionic strength stabilizes particles; closely mirrors true field conditions.
- Gelrite / Bacteria ----Mixing nanoparticles with bacteria lawns ensure consistent ingestion during feeding.

Summary

C. elegans bridges the gap between laboratory testing and real-world soil ecology. Its high sensitivity across behavioral, physiological, and genetic levels makes it an essential tool for ensuring that future nano-agricultural products are both effective and environmentally safe.By using C. elegans for rapid biological screening, researchers are learning how to modify nanoparticle surfaces (such as adding PEG or protein coatings) to significantly lower their toxicity to soil life.

Galleria mellonella (The Greater Wax Moth)

🔊 1. The Highest Ultrasonic Hearing in the Animal Kingdom

Wax moth larvae grow up to become moths that possess the most acute high-frequency hearing ever recorded in nature—capable of detecting sound frequencies up to 300 kHz.

For comparison, humans hear up to 20 kHz, and bats navigate around 100–150 kHz. Evolution gave G. mellonella this extreme hearing to detect bat echolocation calls from far away.

2. The Plastic-Eating "Plastivore"

G. mellonella larvae possess specialized gut microbes and enzymes capable of biodegrading polyethylene (PE)—one of the hardest-to-recycle commercial plastics.

A larva can chew through and metabolize plastic film within hours. In nanotoxicology, researchers exploit this unique digestive ability to test how microplastics and nanoplastics degrade directly inside a living gut environment.

🌡 3. Mammalian Temperature Tolerance (37°C)

Unlike many insect models (like fruit flies, Drosophila) that die or slow down at higher temperatures, G. mellonella larvae can comfortably thrive at 37°C (98.6°F)—human body temperature.

This feature makes G. mellonella indispensable for nanomedicine, as researchers can inject human targeted drugs or nanoparticles into the larvae and observe real-time biological reactions at exact human physiological temperatures.

💉 4. Precise Micro-Dosing Capability

Because G. mellonella caterpillars are relatively large (~2 to 3 cm) compared to nematodes, researchers can use fine Hamilton syringes to perform exact quantitative micro-injections into their prolegs.

This allows scientists to inject precise nanogram doses of nanoparticles directly into their hemolymph (bloodstream), providing accurate dosage control that is impossible with smaller soil organisms.

Why *Galleria mellonella* is the Ideal Sentinel

When nanoparticles enter a biological body, immune cells known as haemocytes in G. mellonella act as the primary defense. Scientists observe several distinct cellular reactions to gauge nanomaterial hazards:

Nanomaterial Exposure

1. Melanisation(Visible Body Darkening)
2. Phagocytosis & ROS (Cellular engulfment)
3. Nodulation &Granuloma Formation

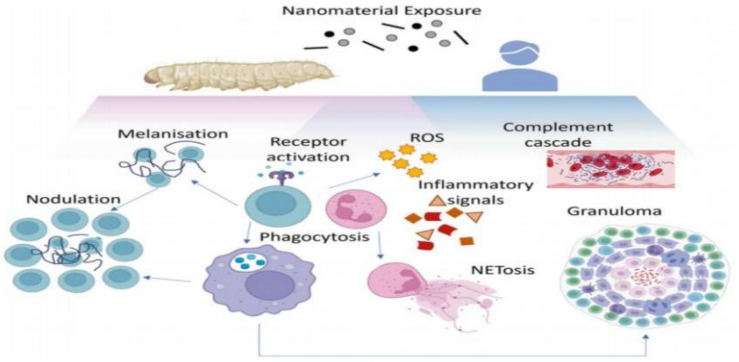
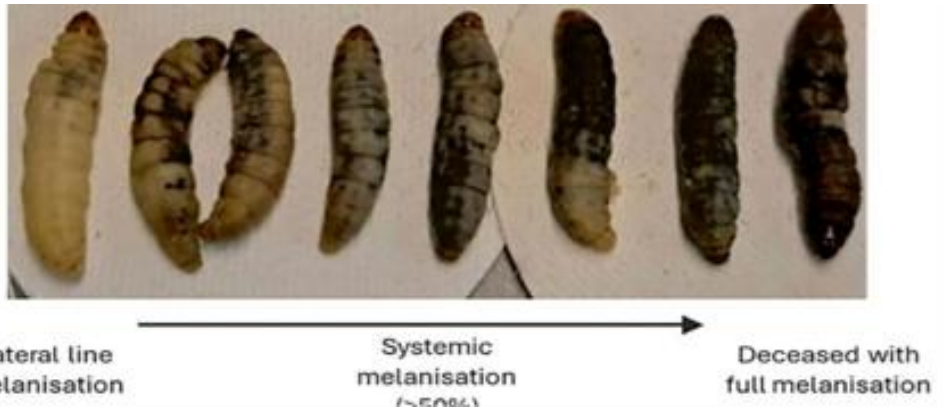


Fig. 12.4 Similarities between G. mellonella and rodent responses to foreign pathogens which may be exploited for hazard assessment of nanomaterials. (Adapted from Smith and Casadevall 2021)

1.Progressive Melanisation (Visual Health Indicator)

One of the most valuable features of G. mellonella is that its immune activation is visible to the naked eye through melanisation.



Upon recognizing foreign nanomaterials, the larva triggers melanin production as an immune response. Healthy larvae remain pale/cream-colored, but progressively shift to lateral spotty darkening and eventually complete body blackening (full melanisation) if the dose is lethal.

2.Phagocytosis and Oxidative Burst

Insects possess specialized immune cells—such as plasmatocytes and granular cells—that function similarly to mammalian neutrophils and macrophages. These cells engulf foreign nanoparticles via phagocytosis. Inside the cell, NADPH oxidase triggers the production of Reactive Oxygen Species (ROS) to break down the particles, mimicking human neutrophil activity.

3.Nodulation and Granuloma Formation

If a nanoparticle is persistent and cannot be broken down (such as silica or graphene oxide), haemocytes cluster around the particles to enclose them, forming nodules. These insect nodules closely resemble granulomas in human lungs—a key marker of chronic inflammatory damage.

Molecular Immunity & Extracellular Traps (NETosis)

G. mellonella utilizes Toll and Toll-like receptor (TLR) pathways, which activate transcription factors to produce antimicrobial peptides (AMPs) when exposed to stress.

When overwhelmed by nanomaterials such as silver, gold, or graphene oxide, immune cells release Extracellular Traps (NETosis)—web-like strands of DNA decorated with antimicrobial enzymes to entrap foreign materials.

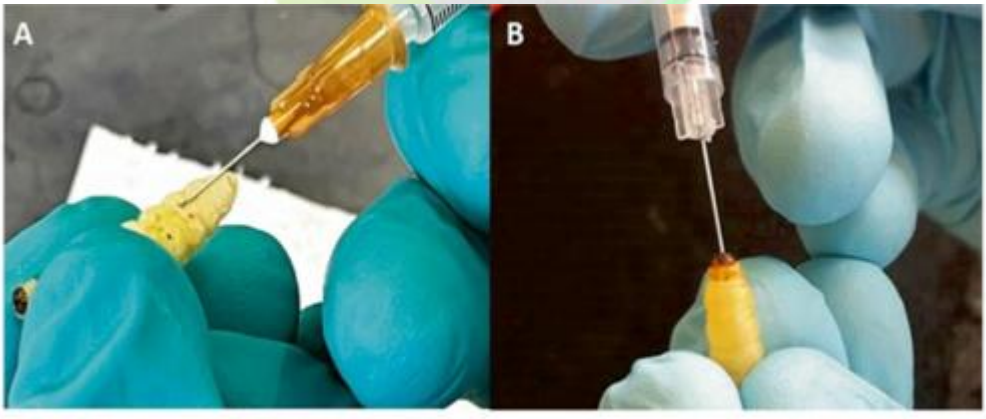


Fig. 12.5 (**a**) Larval inoculation via intra -haemocoel injection. (**b**) Inoculation via force feeding

Blood Clotting and Cardiovascular Testing

In agricultural and medical applications, nanoparticles often enter circulatory fluids. Haemolymph clotting in G. mellonella relies on transglutaminases homologous to human

clotting Factor XIIIa. This allows researchers to use moth larvae to test whether a new nanoparticle causes dangerous blood clotting or thrombosis.

Summary

The wax moth larva *Galleria melella* provides an elegant, rapid, and ethical platform to screen emerging nanomaterials. By monitoring clear visual markers like melanisation alongside cellular responses like granuloma formation, scientists can design safer agri-nanotech products—ensuring technological innovation without compromising environmental or biological health.

Overall view of this article why it is matters to farmers!!

Safe Nano-Inputs: Using C. elegans and G. mellonella ensures new nano-fertilizers and nano-pesticides boost crop yields without harming soil microbes or underground ecosystems.

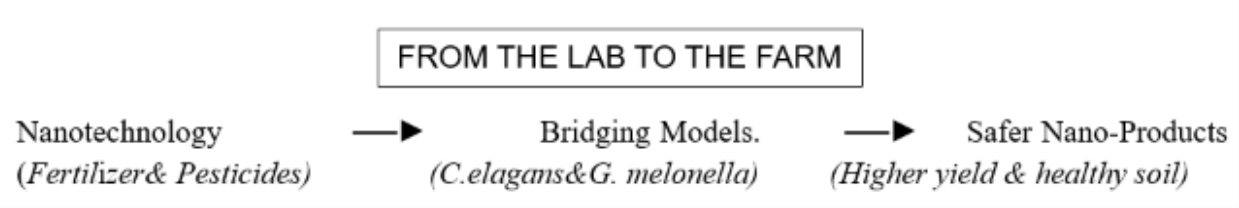
Faster & Cheaper Products: Fast invertebrate testing drastically reduces lab costs and safety screening time, bringing affordable nano-agricultural tools to farmers much quicker.

Farmworker Safety: Because wax moth larvae mirror mammalian immunity, testing verifies that handling new nano-formulations is safe for farmers and field workers.

Long-Term Soil Health: Early screening ensures nanoparticles leave zero toxic residue in soil or groundwater, preserving farm fertility for future generations.

Conclusion:

The fusion of nanotechnology and agriculture promises a new green revolution—from smart nano-fertilizers that boost crop yields to nano-encapsulated pesticides that target pests with pinpoint precision. However, ensuring that these high-tech inputs are safe for agricultural ecosystems requires innovative, rapid, and ethically sound testing tools.



The Genetic & Reproductive Sentinel *(C. elegans):* With its rapid three-day life cycle, fully mapped genetic structure, and extreme sensitivity to soil toxicity, this soil nematode acts as an early warning system. It reveals how nanoparticles impact soil health, worm reproduction, and long-term ecosystem balance across multiple generations.

The Cellular & Immune Sentinel *(G. mellonella):* With an immune system that mirrors mammalian cellular responses, wax moth larvae provide immediate, visual feedback (such as

body darkening or melanisation) on whether a nanoparticle triggers severe inflammation, tissue damage, or cellular toxicity.

Reference

Avila DS, Adams MR, Chakraborty S, Aschner M (2011) Chapter 16—Caenorhabditis ele-Gans as a model to assess reproductive and developmental toxicity. In: Gupta RC (ed) Reproductive and developmental toxicology. Academic, San Diego. https://doi.org/10.1016/ B978-0-12-382032-7.10016-5

Chakravarty B (2022) The evolving role of the Caenorhabditis elegans model as a tool to Advance studies in nutrition and health. Nutr Res 106:47–59. https://doi.org/10.1016/j. Nutres.2022.05.006

Tyne W, Lofts S, Spurgeon DJ, Jurkschat K, Svendsen C (2013) A new medium for Caenorhabditis Elegans toxicology and nanotoxicology studies designed to better refect natural soil solution Conditions. Environ Toxicol Chem 32:1711–1717. https://doi.org/10.1002/etc.2247

Cé R, Silva RC, Trentin DS, Marchi JGB, Paese K, Guterres SS, Macedo AJ, Pohlmann AR (2020) Galleria mellonella larvae as an in vivo model to evaluate the toxicity of polymeric Nano cap-Sules. J Nanosci Nanotechnol 20:1486–1494

Campbell JS, Pearce JC, Bebes A, Pradhan A, Yuecel R, Brown AJP, Wakefeld JG (2024) Characterising phagocytes and measuring phagocytosis from live Galleria mellonella larvae. Virulence 15:2313413

Volume: 06 Issue No: 09

IMPORTANCE OF HYDROPONIC TECHNIQUE IN AGRICULTURE

Article ID: AG-VO6-I09-138

D.L. Bagdi

Department of Plant Physiology, S.K.N. College of Agriculture, Jobner (Rajasthan)-303329, India

---

Introduction

Hydroponics is a method of growing plants without soil, in which plant roots receive water, essential mineral nutrients, oxygen, and other necessary conditions through a nutrient solution or a suitable inert growing medium.

Technique of Hydroponics

The basic technique involves:

1. **Selection of crop and healthy seedlings** – Lettuce, tomato, cucumber, capsicum, spinach, strawberry and many herbs are commonly grown.
2. **Preparation of nutrient solution** – Water is supplied with essential nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, sulphur and micronutrients.
3. **Root support** – Plants are supported using a suitable medium or net pots.
4. **Supply of nutrient solution** – The solution is delivered directly to the root zone.
5. **Oxygen supply** – Adequate oxygen is maintained around the roots, particularly in water-based systems.
6. **Control of pH and EC** – Nutrient solution pH and electrical conductivity are regularly monitored.
7. **Environmental control** – Light, temperature, humidity and ventilation are managed according to the crop.
8. **Regular monitoring** – Nutrient concentration, water level, root health and plant growth are checked regularly.

Hydroponics is important because it:

i. Produces crops without agricultural soil.

ii. Allows cultivation in water-scarce and arid regions.
iii. Uses water more efficiently than conventional soil cultivation.
iv. Permits crop production in urban areas, rooftops and protected structures.
v. Provides better control over plant nutrition.
vi. Can produce high-quality vegetables throughout much of the year.
vii. Reduces problems associated with soil-borne diseases and poor soil fertility.
viii. Makes intensive production possible in a small area.
ix. Supports protected cultivation and modern commercial horticulture.

Growing Media Used in Hydroponics: Hydroponic media should provide root support, aeration and adequate moisture retention. Common media include:

Medium	**Main characteristics**
Cocopeat (coconut coir)	Good water-holding capacity and aeration
Perlite	Lightweight and provides good aeration
Vermiculite	Good moisture and nutrient retention
Rockwool	Good water and air balance; widely used in commercial systems
Expanded clay pellets (LECA)	Excellent drainage and root aeration
Sand	Provides physical support but requires careful management
Gravel	Good drainage and support
Rice husk	Low-cost material with useful aeration properties

Methods of Hydroponics

A. Wick System: A wick draws nutrient solution from a reservoir to the growing medium by capillary action.

Advantages: Simple, inexpensive and suitable for small-scale production.

B. Deep Water Culture (DWC): Plant roots remain suspended in a nutrient solution while an air pump supplies oxygen.

Suitable crops: Lettuce, leafy vegetables and herbs.

C. Nutrient Film Technique (NFT): A thin film of nutrient solution continuously flows through channels over the plant roots and returns to a reservoir.

Advantages: Efficient use of water and nutrients and suitable for commercial leafy-vegetable production.

D. Drip Hydroponics: Nutrient solution is delivered to individual plants through drip emitters.

Suitable crops: Tomato, cucumber, capsicum and other larger plants.

E. Ebb and Flow (Flood and Drain): The growing bed is periodically flooded with nutrient solution and then drained back into the reservoir.

F. Aeroponics: Plant roots are suspended in air and periodically sprayed with a fine nutrient mist.

Advantage: Excellent root aeration and efficient nutrient delivery.

G. Kratky Method: Plants grow with their roots partly submerged in a nutrient solution without continuous pumping or aeration. It is particularly useful for simple, small-scale hydroponic production.

Hydroponics is Used for What Purposes

Hydroponics is used for:

i. Production of vegetables and leafy greens.
ii. Production of herbs and spices.
iii. Production of tomato, cucumber, capsicum and strawberry.
iv. Nursery and seedling production.
v. Urban and rooftop farming.
vi. Commercial protected cultivation.
vii. Cultivation where soil is poor, contaminated or unavailable.
viii. Crop production in arid and water-limited areas.
ix. Research on plant nutrition, root growth and plant physiology.
x. Controlled-environment agriculture.
xi. Food production in places where conventional agriculture is difficult, including some space and remote-environment research applications.

Benefits of Hydroponics

1. **Higher water-use efficiency** – Water can be recirculated and reused.
2. **Efficient nutrient management** – Nutrients can be supplied directly to the root zone.
3. **No soil requirement** – Useful where soil is infertile, degraded or unavailable.
4. **Higher productivity per unit area** – Plants can be grown at relatively high density.

5. **Year-round production** – Especially when combined with greenhouse or controlled-environment technology.
6. **Reduced weed problems** – There is little or no agricultural soil in which weeds can establish.
7. **Better control of plant growth** – Water, nutrients and environmental conditions can be carefully managed.
8. **Suitable for urban agriculture** – Can be installed on rooftops, balconies and other limited spaces.
9. **Cleaner produce** – Soil particles are not directly associated with the growing system.
10. **Potentially lower pesticide requirement** – Particularly in protected systems, although pest management is still necessary.

Merits of Hydroponics

Major merits

i. Soil is not required.
ii. Efficient use of water and fertilizers.
iii. High production from a small area.
iv. Better control of plant nutrition.
v. Suitable for poor or non-arable land.
vi. Reduced weed problems.
vii. Suitable for protected and urban cultivation.
viii. Easier automation of irrigation and nutrient supply.
ix. Potential for continuous production.
x. Useful for research and teaching in plant science.

Demerits of Hydroponics

i. High initial investment for commercial systems.
ii. Requires technical knowledge and regular monitoring.
iii. Electricity may be required for pumps, aeration and environmental control.
iv. Nutrient imbalance can rapidly affect plants.
v. Failure of pumps or power supply can cause rapid crop damage in some systems.
vi. Water-borne diseases can spread rapidly through recirculating systems.
vii. pH and EC must be monitored regularly.

viii. Nutrient solutions need proper preparation and management.

ix. Commercial systems can have relatively high operating costs.

x. Disposal or management of spent nutrient solution requires care to prevent environmental pollution.

xi. Not every crop is equally economical or suitable for hydroponic production.

Hydroponics and National Economy

Hydroponics can contribute to the national economy by:

i. Increasing production of high-value horticultural crops.

ii. Improving productivity per unit of land and water.

iii. Supporting urban and peri-urban agriculture.

iv. Creating employment in greenhouse construction, nursery production, crop management, marketing and processing.

v. Reducing dependence on fertile agricultural land for certain crops.

vi. Supporting production in water-scarce and soil-constrained regions.

vii. Generating income through high-value vegetables, herbs and specialty crops.

viii. Promoting modern agricultural technology and entrepreneurship.

Conclusion:

Hydroponics is a modern soil-less cultivation technique that provides plants with water, nutrients, oxygen and suitable environmental conditions without conventional soil. Its major advantages are efficient water and nutrient use, high productivity, better control of plant growth and suitability for urban, protected and water-scarce agriculture. However, its success depends on proper nutrient management, technical skill, equipment and regular monitoring. Therefore, hydroponics has considerable potential for sustainable horticulture, high-value crop production and efficient use of limited land and water resources, particularly when the system and crop are selected according to local economic and environmental conditions.

Acknowledgements: I would like to thanks the AICRP on AZF, CIAH, Bikaner for the financial support of publication of this article.

Competing interests: The authors declare that they have no competing interests.

Volume: 06 Issue No: 09

ROLE OF NANOTECHNOLOGY IN IMPROVING SEED GERMINATION AND CROP GROWTH

Article ID: AG-VO6-I09-139

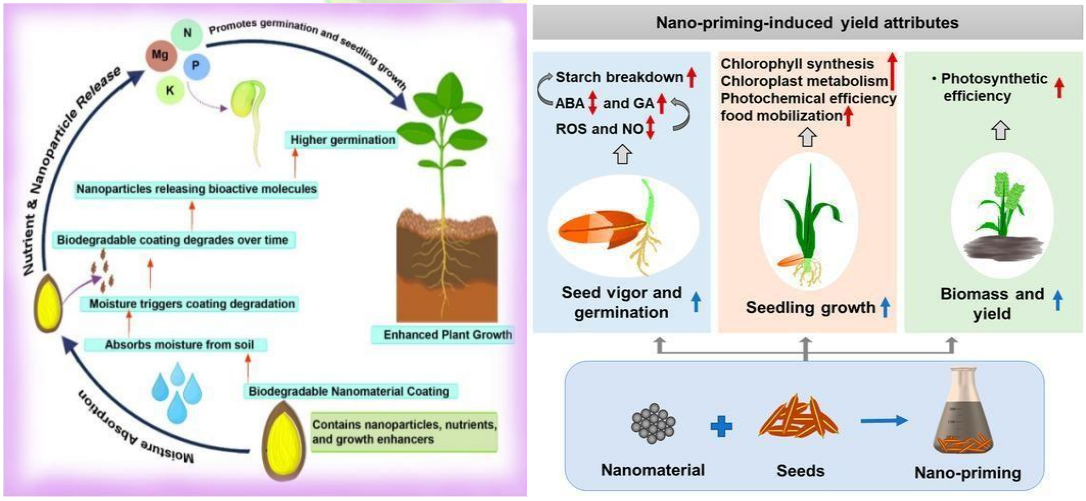
Poorni Sri M

1st M.Sc.(Ag) Nanoscience and Technology, Tamil Nadu Agricultural University

Coimbatore, Tamil Nadu, India

Introduction

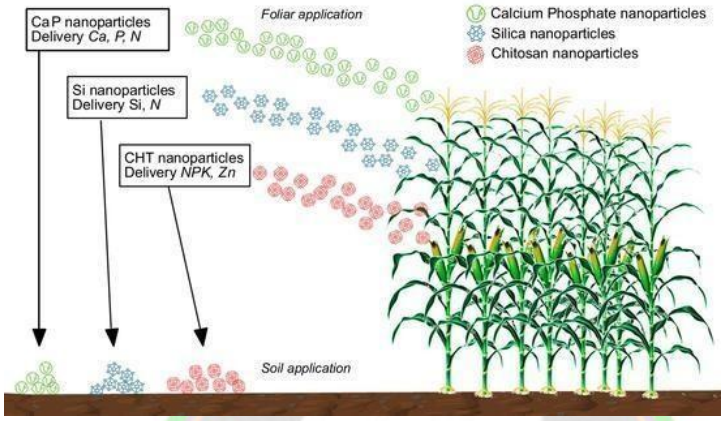
Agriculture is facing a difficult challenge: farmers need to produce more food while using water, fertilizers and pesticides more efficiently. At the same time, crops are increasingly exposed to drought, salinity, high temperatures, heavy metals, pests and diseases. One emerging technology that may help address some of these challenges is nanotechnology. Nanotechnology works with extremely small materials, commonly in the approximate range of 1–100 nanometres. At this scale, materials can have unusual surface, chemical and biological properties that make them useful for delivering nutrients or influencing plant processes.



In agriculture, nanoparticles are being investigated as seed treatments, nanofertilizers, nanocarriers, soil amendments and foliar sprays. One particularly interesting application is nano-

priming, in which seeds are exposed to an appropriate concentration of nanoparticles before sowing.

Research indicates that nano-priming can influence water uptake, enzyme activity, hormones, antioxidant systems and early seedling development.



What is nano-priming?

Traditional seed priming involves partially hydrating seeds before sowing so that important metabolic processes begin without allowing the seed to germinate completely. Nano-priming takes this idea a step further**.** Seeds are treated with a suspension containing suitable nanoparticles. Depending on the material, the nanoparticles can interact with the seed surface and influence water absorption, nutrient availability and biochemical signalling. Studies have reported effects on seed germination, seedling vigour, stress tolerance and subsequent plant growth, although responses vary considerably with nanoparticle type, concentration, crop species and treatment conditions.

How does nanotechnology improve seed germination?

1. Better water uptake

Water is the first major requirement for germination. When a dry seed absorbs water, it swells and activates enzymes and metabolic pathways. Some nanomaterials can influence the physical properties of the seed surface and water movement. Research on nano-priming suggests that nanoparticles can affect aquaporins, which are membrane proteins involved in water transport. Improved water uptake can help initiate the metabolic processes required for germination. This is particularly interesting under conditions where water availability is limited.

2. *Activation of enzymes*

A germinating seed must mobilize the food reserves stored inside it. For example, starch stored in cereal seeds must be converted into soluble sugars that can provide energy to the growing embryo. Nano-priming has been associated with increased activity of enzymes such as amylase, which participates in starch breakdown. This can contribute to earlier emergence and stronger seedlings.

3. *Regulation of reactive oxygen species*

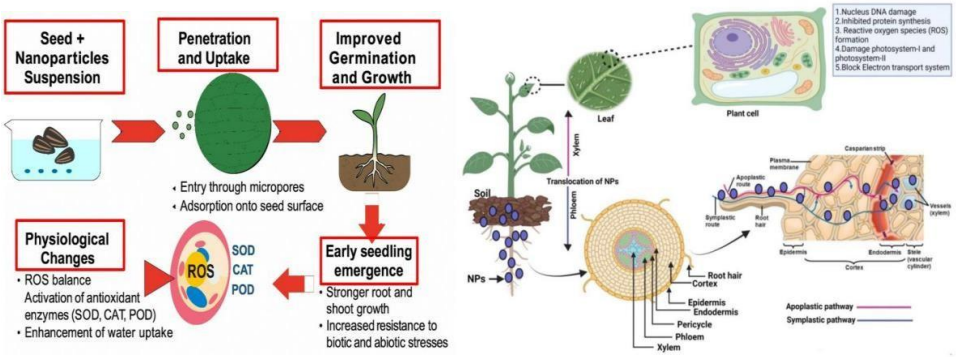
Reactive oxygen species, or ROS, are often thought of simply as harmful molecules. In reality, plants use controlled amounts of ROS as signalling molecules. During germination, an appropriate ROS level can participate in signalling pathways associated with cell-wall modification, metabolism and seedling development. Nano-priming can influence the balance between ROS production and antioxidant defence systems. The important point is that more nanoparticles do not necessarily mean better results. An appropriate concentration may stimulate useful signalling, whereas excessive exposure can produce oxidative stress and inhibit germination.

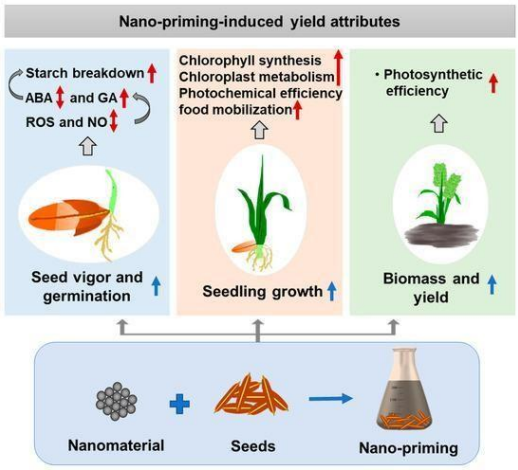
4. *Influence on plant hormones*

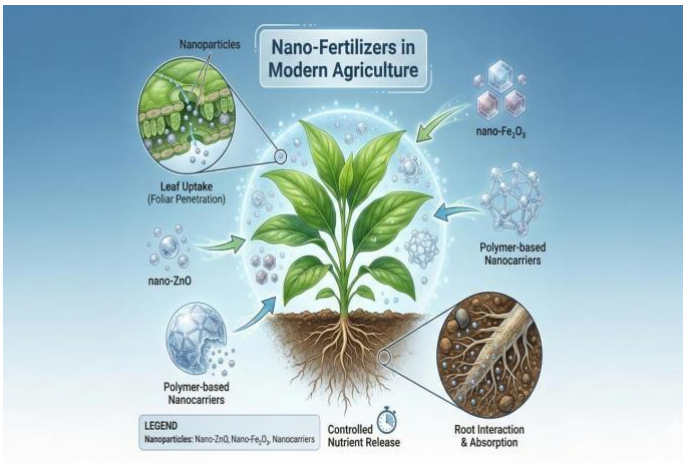
Plant hormones such as gibberellins (GA) and abscisic acid (ABA) have important and sometimes opposing roles during seed dormancy and germination. Nano-priming can influence hormone balance and related signalling pathways. For example, changes in the ABA/GA balance can help shift a seed from dormancy toward germination. This is one reason nano-priming is more than simply supplying nutrients—the nanoparticles can also act as biochemical stimulators

Nanotechnology and seedling growth

Once a seed germinates, the next challenge is establishing a healthy seedling.







Nanoparticles may influence several processes associated with early plant development:

- root growth
- shoot development
- chlorophyll formation
- photosynthesis
- nutrient absorption
- antioxidant activity
- water-use responses
- tolerance to environmental stress.

Reviews of nano-priming report improvements in seedling vigour and plant growth under appropriate treatment conditions. A stronger root system can be especially valuable because roots determine how effectively a young plant accesses water and nutrients from the soil.

Role of nanofertilizers in crop growth

Another major agricultural application is the development of nanofertilizers. Conventional fertilizers can be lost through leaching, runoff, volatilization or fixation in soil Nanotechnology offers the possibility of designing materials that deliver nutrients more precisely or release them gradually.

Nanofertilizers can potentially contain or carry nutrients such as:

- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)

- Zinc (Zn)
- Iron (Fe)
- Silicon (Si)
- Copper (Cu)
- other micronutrients.

Their small size and high surface-area-to-volume ratio can provide opportunities for controlled nutrient delivery. However, actual nutrient-use efficiency depends strongly on the nanoparticle formulation, soil conditions, crop species and application method.

This does not mean that nanofertilizers automatically outperform conventional fertilizers in every field. Field conditions are much more complicated than laboratory experiments, and this remains an important area of research.

Conventional fertilizer	**Nano-enabled fertilizer**
Nutrient can be rapidly released	Potential for controlled/slow release
Greater possibility of nutrient loss	Can potentially improve nutrient-use efficiency
Often applied in relatively large quantities	Potential for more precise delivery
Less control over release	Release can potentially be engineered

Important nanoparticles used in agriculture Zinc oxide nanoparticles

ZnO nanoparticles have attracted considerable attention because zinc is an essential micronutrient for plants. Appropriate zinc nanoparticle treatments have been associated with improved germination, nutrient status, antioxidant responses and growth in various crops.

Research also suggests potential benefits under drought, salinity and heavy-metal stress. However, excessive zinc or high nanoparticle concentrations can become toxic. Therefore, dose is critical.

Iron nanoparticles

Iron is essential for chlorophyll formation, electron transport and several metabolic processes.Nano-scale iron materials are being investigated as approaches for improving iron delivery and plant nutrition. Reviews indicate that iron nanoparticles can influence nutrient

uptake and germination, although their effectiveness depends on particle properties and application conditions.

Silicon nanoparticles

Silicon nanoparticles are receiving increasing attention because silicon can help plants cope with several stresses. Research has reported potential roles in:

- drought tolerance
- salt tolerance
- metal stress
- pathogen resistance
- antioxidant defence
- photosynthetic performance
- seed germination and seedling growth.

For example, silicon nanoparticle seed priming has been studied in crops such as wheat, maize, cucumber and lentil under stress conditions.

Nanotechnology against drought and salinity

Drought and salinity are two major environmental stresses that can interfere with germination and plant growth.Under drought, seeds may not absorb enough water to initiate normal germination. Salinity creates an additional problem because high concentrations of salts reduce water availability and can cause ionic stress. Silicon nanoparticles, for example, have been investigated for their ability to improve plant responses to salt and drought stress.

Proposed mechanisms include regulation of antioxidant systems, photosynthesis and sodium/potassium balance. Nano-priming may therefore be particularly interesting for agriculture in environments where crops regularly experience environmental stress. After germination, the plant must produce its own food through photosynthesis. Nanomaterials can influence photosynthetic performance indirectly through improved nutrient availability, chlorophyll production, antioxidant protection and stress tolerance. Some studies report increased chlorophyll and improved photosynthetic efficiency following appropriate nanoparticle treatments. Nano-priming reviews also describe effects extending from germination into later plant development. The strength of this relationship, however, differs between crops and experimental conditions.

Nanoparticles as carriers for agricultural chemicals

Nanotechnology is not limited to nutrients. Nanoparticles can potentially act as carriers for:

- fertilizers
- plant-growth regulators
- pesticides
- biological molecules
- other agricultural compounds.

The objective is to deliver the active material where it is needed and potentially control its release. For example, biodegradable nanomaterial coatings are being investigated for seeds. Such coatings can absorb moisture and release nutrients or biologically active substances during germination. This approach could eventually support precision agriculture, where inputs are delivered according to crop requirements rather than simply applying large quantities across an entire field.

The major limitation: "Nano" does not automatically mean safe

This is one of the most important points. Nanoparticles can have beneficial effects at one concentration and harmful effects at another. Their biological effects can depend on:

- particle size
- shape
- surface charge
- chemical composition
- concentration
- exposure time
- crop species
- soil properties
- pH
- temperature
- method of application.

Metal nanoparticles such as zinc, copper, silver and titanium-based materials can produce very different biological responses depending on these factors. Excessive concentrations can inhibit germination, damage roots or cause oxidative stress. There are also questions about what happens to nanoparticles after they enter soil, water, plants and agricultural ecosystems.

Researchers therefore emphasize the need for long-term toxicity studies, environmental fate studies and standardized application protocols.

From laboratory research to farmers' fields

One of the biggest challenges is the gap between promising laboratory results and practical agricultural application. A nanoparticle may work very well in a controlled experiment, but a farmer's field contains:

- different soil types
- microorganisms
- changing temperatures
- irregular rainfall
- different pH and nutrient levels
- complex interactions between roots and soil
- different crop varieties.

Consequently, successful agricultural nanotechnology requires field trials, economic evaluation, safety assessment and appropriate regulation. Reviews published in recent years specifically identify field validation, toxicity and environmental consequences as important research gaps

Future prospects

Nanotechnology is moving from an experimental research area toward a potential component of precision and sustainable agriculture. In the future, nanoparticles may not simply be used as fertilizers; they could function as smart delivery systems, sensors, stress-management tools, seed treatments and carriers for biological molecules. The greatest opportunity is to make agricultural inputs more precise—delivering the right substance to the right plant tissue at the right time and in the right amount.

1.*Development of smart seed nano-coatings*

One of the most promising future applications is the development of multifunctional nano-coatings for seeds**.** Future seed coatings could contain combinations of:

- micronutrients such as Zn, Fe and Si;
- plant-growth-promoting compounds;
- beneficial microorganisms or their metabolites;
- natural polymers such as chitosan;
- controlled-release materials;

- compounds that protect seeds against pathogens.

Instead of releasing everything immediately after sowing, advanced coatings could be designed to respond to soil moisture, temperature, pH or root-zone conditions. This could make seed treatment more efficient while reducing unnecessary application of agricultural inputs.

2. *Nano-priming for climate-resilient crops*

Climate change is expected to increase the frequency and severity of stresses such as drought, salinity and high temperature in many agricultural regions. Future research is likely to focus on using nano-priming to improve seed resilience before plants encounter stress. For example, researchers are investigating whether suitable nanoparticles can prime antioxidant systems and improve physiological responses to drought and salinity. In the future, nano-priming could therefore become part of a broader strategy for producing climate-resilient planting material.

3. *Precision nanofertilizers*

Conventional fertilizer application can result in nutrient losses through leaching, runoff, volatilization and fixation. Future precision nanofertilizers could be designed to release nutrients gradually and closer to the plant's requirements. For example, a nanocarrier could contain nitrogen, phosphorus or micronutrients and release them progressively rather than making the entire nutrient dose immediately available. Such systems could potentially improve nutrient-use efficiency and reduce environmental losses.

Conclusion

Nanotechnology offers an exciting new approach to improving seed germination, seedling establishment and crop growth. At the seed stage, nano-priming can influence water uptake, enzyme activity, ROS signalling, hormone balance and metabolism. During later growth, nanomaterials may improve nutrient delivery, photosynthesis, antioxidant defense and tolerance to drought, salinity, heavy metals and pathogens. The technology is especially promising because nanoparticles can potentially function not only as nutrients but also as carriers, stimulators and controlled-release systems. The same nanoparticle can have beneficial or harmful effects depending on its dose, formulation and environmental conditions. The real promise of agricultural nanotechnology is therefore not simply “smaller fertilizers,” but smarter delivery of resources to seeds and plants—using the right material, at the right concentration, at the right time.

References

Oliveira, H. C. et al. (2021). Nanotechnology Potential in Seed Priming for Sustainable Agriculture. *Nanomaterials*, 11, 267.

Nile, S. H. et al. (2022). Nano-priming as emerging seed priming technology for sustainable agriculture—recent developments and future perspectives. *Journal of Nanobiotechnology*.

Wang, J. et al. (2024). Nanopriming boost seed vigor: Deeper insights into the effect mechanism**.** *Plant Physiology and Biochemistry*.

Volume: 06 Issue No: 09

META ANALYSIS IN BLACKGRAM NUTRIENT MANAGEMENT FOR GROWTH PARAMETER

Article ID: AG-VO6-I09-140

K.Maruthupandi

Department of Agronomy, Assistant Professors , Gandhigram Rural Institute-Deemed to be University, Gandhigram, Dindugal dt, TamilNadu, India-624302.

Abstract

The field experiment was conducted during Zaid season of 2022 at the Crop Research Farm, Department of Agronomy, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (U.P.) India. To study the Influence of Growth Regulators on the growth of Black gram. The treatments consist of levels of Gibberellic Acid (GA_3 – 15 ppm, GA_3 – 30 ppm, GA_3 – 45 ppm) and Salicylic acid (SA – 50 ppm, SA – 75 ppm, SA – 100 ppm). The soil of experimental plot was sandy loamy in texture, nearly neutral in soil reaction (pH 7.8), low in organic carbon (0.35%). Results revealed that application of GA3 45 ppm + 50 ppm Salicylic acid (T_{10}) recorded with plant height (40.08 cm), plant dry weight (7.13 g/plant), were also recorded in treatment T_{10} GA3 45 ppm + 100 ppm Salicylic acid at 15 & 40 DAS. Integrated nutrient management on growth parameters of black gram under field conditions, during (kharif) season of 2017. The research was conducted with nine treatments, in which one control, 100% recommended dose of fertilizer alone and seven treatments with combination of organic and inorganic fertilizers i.e. farm yard manure 5 t ha^{-1}, vermicompost 2.5 t ha^{-1},poultry manure 2.5t ha^{-1} ,nitrogen 5 kg ha^{-1} and phosphorus 11 kg ha^{-1} respectively and Rhizobium along with biofertilizer as used for seed treatment. Observations were recorded on growth parameters such as plant height (cm), number of leaves $plant^{-1}$ and number of branches $plant^{-1}$. An application of 100% recommended dose of fertilizer gave maximum plant height (51.37 cm) at 85 DAS (days after sowing), number of leaves (26.60) $plant^{-1}$ and branches $plant^{-1}$ 14.00 at 60 DAS in treatment T_1 as compared to others. Among the different grain legumes, blackgram is a well-known leguminous crop A field experiment was conducted

during *Autumn* season of 2018 and 2019, to evaluate the effect of humic acid (HA) application on growth of blackgram The treatments were: Control (sowing of dry seed) (T_1); Seed priming (soaking) in water (T_2); Seed priming in 0.5% humic acid solution (T_3); Seed priming in 1% humic acid solution (T_4); Seed priming in 2% Humic acid solution (T_5); Soil application of humic acid @1 kg/ha (T_6); Soil application of humic acid @ 2 kg/ha (T_7); Soil application of humic acid @1 kg/ha + 10 t compost/ha (T_8); Soil application of humic acid @ 2 kg/ha + 10 t compost/ha (T_9); Foliar application of 0.01% humic acid solution 25 days after sowing (DAS) (T_{10}); Foliar application of 0.05% humic acid solution (25 DAS) (T_{11}); Foliar application of 0.1% humic acid solution (25 DAS) (T_{12}).Soil application of humic acid along with compost had significant on growth of blackgram treatment was obtained from the treatment T_9 and the second-best treatment was T_8.

Keywords: Black gram, Foliar Spray, Growth, Humic Acid, RDF

Introduction

Black gram is the most important legume crop and India alone produce more than two-third of the world‟s production (Saini and Jaiwal, 2002) as food, feed and industrial raw material and ranks as the third important pulse crop in India (Selvakumar *et al.*, 2012). Total black gram production was 3280 thousand tonnes; of which percentage share in 13.48% during 2017-18 (Anonymous, 2018). Due to its wider adaptability, it is grown across a wide range of agro-ecological zones. In Punjab, cultivation is about 1.1 million tons of mash every single year from about 2.2 thousand hectares of area with an average productivity of 539 kg per hectare in 2015-2016. Black gram considered as a staple food for about 900 million consumers and about one third of all underfed children. After green revolution cereal grain production increased, which resulted in sharp decline of per capita production and availability of pulses with record of 4.0 million tonnes of imported pulses in 2012-13 (Singh *et al*., 2017). The term pulse refers as the dried seed/grain. In India major pulse crops grown are chickpea, pigeonpea, mung bean, urd bean and lentil etc. These are highly nutritious, rich in dietary fiber, sugar and almost contains no fats (Kokani *et al*., 2014).

Leguminosae is the family that includes blackgram. The significant pulse crop grown throughout India's various agro-climatic zones is black gram. Although this crop is farmed during the Kharif and Rabi seasons, the majority of its land is planted during the former, when intercropping with crops like sorghum, pearl millet, maize, cotton, castor, and pigeon pea is

highly common. In terms of India's main pulse crops, black gram holds a significant position (Fatima Anaya *et al*..2015, Ferdowsi noor *et al*.,2017, Vekaria *et al*.,2017). A complete array of nutrients, including 20 to 25% protein, 40 to 47% starch, ash lipids, carbs, and important vitamins, may be found in black gramme (Neelambari *et al*.,2018, Nikita Nehal *et al*.,*2018*, Pradip Kumar Saini *et al.,* 2017). In 2012– 2013, the total area, production, and productivity of black gramme in India were 3.11 million hectares, 1.90 million tonnes, and 611 kg/ha, respectively (Anonymous *et a*l., 2018). A vast class of tetracyclic diterpenoid plant growth agents is known as the gibberellins. In order to control plant growth, GA_3 acts as a hormone, and this knowledge dates back to the 1950s (Solanki Mital *et al*., 2017). Salicylic acid, also known as orthohydroxybenzoic acid, is a secondary metabolite that functions similarly to chemicals that control development. important in increasing the crop's growth (Reham Dawar *et al*., 2020). Its ranked third among all pulses in India and contributes to 10% of the national pulse production from an area of 13% of total pulse crop area.

Blackgram is rich in nutrients such as protein (25-28%), oil (1-1.5%), carbohydrate (60-65%), essential mineral (K, Ca, Zn), various vitamins (Vit C, B), fibre (3.5-4.5%) and antioxidant compounds that can help to boost the human health (Lavanya *et al*., 2022 and Patial *et al*., 2022). It is also rich in amino acids like methionine, cysteine and lysine. Both production and area under this crop lay decreased during last decade. The targeted production and productivity are possible by way of harnessing the yield gap by growing pulses in new niches *i.e*., precision farming, quality inputs, soil test based integrated nutrient management and mechanized method of pulse cultivation complimented with generous governmental policies and appropriate funding support to implementing stake holders.

Maintenance of soil organic material at a satisfactory level is needed for sustainable and high productivity of crops over long periods (Govindasamy, 2002). Humic acid (HA) is the major component of most of the organic fertilizers and the most active components of soil and organic matter might help to overcome these production constraints in the pulse crops. Humic substances arise from chemical and biological degradation of plant and animal residues and from synthetic activities of micro-organisms (Schnitzer, 1968). It enriches the soil and facilitates fertilizer nutrients to reach their maximum potential in improving plant growth (Nithila *et al*.,2013).

Discussion:

Plant Height

At 60 DAS, the significantly higher plant height of (40.08 cm) was recorded with treatment-10 (GA_3 45 ppm + 100 ppm salicylic acid at 15 & 40 DAS). However, T_9 GA_3 45 ppm + 75 ppm salicylic acid at 15 & 40 DAS (39.34cm) was found to be statistically at par with T_{10} (GA_3 45 ppm + 100 ppm salicylic acid at 15 & 40 DAS). The plant height of Black Gram increased significantly due to with at Harvest, Foliar application of GA3 significantly influenced the black gram plant height (cm).Similar results were reported by Rehem Dawar *et al*. (2020). According to Singh (2008), an improvement in the soil's nutrient status and the creation of a conducive environment for better root growth through the secretion of growth promoting substances like Gibberellin, cytokinin, and auxin are responsible for the significant increase in the number of pods per plant following seed inoculation with growth regulators.

Plant height is an important index of plant growth at a given time during the growth period. it is revealed that the plant height has positive respond to different humic acid application doses and methods. Soil application of humic acid @ 2 kg ha^{-1} along with farm compost @ 10 t ha^{-1} (T_9) recorded higher plant height (*i.e*., 45.62 cm) in 2018 and also in 2019 (51.07 cm). However, the minimum plant height was observed in T_1 in 2019 but in 2018, T_2 (receiving N-P-K fertilizers plus seed priming was done with plain water) shows minimum plant height. The plant height was significantly influenced by soil application of humic acid along with compost during both the years.

Soil application and foliar spray of humic acid (HA) significantly increased plant height over other seed treatment and control where no humic acid applied and there is no significant difference between seed priming with control in both the year of experiment. Plant height was recorded more at higher dose of HA at soil with compost. However, seed priming with higher doses of HA (2%) in some cases shows better result than the seed priming with lower doses of HA. The positive effect of humic acid in improving plant height was probably due to synergistic and beneficial effect due to the adequate nutrient availability thus resulted in greater elongation (Singeravel *et al*., 1993). The increased plant height can also justify by Prasad and Prasad (1994) that auxin derivatives are involved in cell division and differentiation also expansion through increasing the plasticity thereby enhancing growth and development.

The effect of integrated nutrient management on recommended dose of fertilizer, farm yard manure, vermi-compost and poultry manure on growth habits of black gram. Thus the results were depicted the following heads. Plant height (cm) of black gram was recorded at three different intervals (30, 60 and 85 DAS) and the influence of organic and inorganic sources .The plant height observations recorded at 30, 60 and 85 DAS were significantly different among the treatments. The maximum plant height at 30 DAS was recorded in T_1 (22.55 cm) followed by T_4 (21.91 cm), T_3 (21.87 cm), T_6 (20.66 cm), T_2 (19.38 cm), T_7 (18.79 cm) and T_8 (18.77 cm), while the minimum plant height was observed inT_5 (18.30 cm). At 60 DAS the maximum plant height was also recorded in T_1 (34.47 cm) which was statistically at par with T_4 (33.27 cm) and the minimum plant height was recorded in T_0 (25.13 cm). Similarly, the maximum plant height at the time of harvest (85 DAS) was recorded in T_1 (51.37 cm) and the minimum height was recorded in T_0 (43.87 cm). The maximum increased in plant height was observed in those plots treated with 100 % RDF and 75 % RDF + 25 % vermi-compost. The possible reason for this could be because the growing pattern and increased seed rate that allows the plant to avoid inter plant competition for nutrients (Rathore *et al*., 2010). Sufficient amount of nutrients from the inorganic fertilizers as well as some from the organic fertilizers improves the cell activities, cell multiplication and luxuriant growth of the plant which could explained the increased in plant height of the crop (Fashina *et al*., 2002). The reduction in the nitrogen at an early growing stage could reduce the rate of photosynthesis which could attribute in the reduction of plant height. Similar findings were also reported by Singh *et al*., (2011).

Number of Leaves

The effect of integrated nutrient management on number of leaves of black gram were found to have no significant difference amongst the treatments at 30, 60 and 85 DAS at the time of harvest At 30 DAS the maximum number of leaves were observed in T_1 (11.53) followed by T_4 (11.20). At 60 DAS the minimum number of leaves were recorded in T_5 (21.13) which was lower by T_1 (26.60) and T_4 (26.60) which were the maximum number of leaves recorded. At the time of harvest (85 DAS), the maximum number of leaves were recorded in T_2 (19.33) which was higher than control T_0 (17.00). The increased in number of leaves per plant were either observed in plots treated with 100 % RDF or plots treated with combination of organic and inorganic fertilizers. Application of fertilizers solely or in combined form improves the soil fertility level as well as nutrients which enables better root development and root nodules

allowing the plant to take up the nutrients with ease which might be the reason for increase in the number of leaves (Rathore *et al*., 2010). Similar finding was also reported by Vadgave (2010).

Number of branches

Branches number plant^{-1} The statistical analysis at an initial stage (30 DAS) revealed that number of branches per plant were found to have no significant difference amongst the treatments but when comparisons were made T_1 (3.67) and T_4 (3.33) were higher than T_0 (2.00) and T_8 (2.00). At 60 DAS the treatments were significantly different between all the treatments and the maximum numbers of branches were observed in T_1 (14.00) followed by T_4 (13.67) which were both higher than control i.e., T_0 (8.00). Reddy *et al*., (2011) reported that the increased in number of branches could be possible because the application of organic and inorganic fertilizers along with biofertilizers due to enhancement of microbial activity in the rhizosphere which enables the roots for the better uptake of nutrients. Similarly, the application of organic and inorganic fertilizers increases the overall growth attributes of the crop due to their synergistic effect Singh *et al*., (2008; 2011).

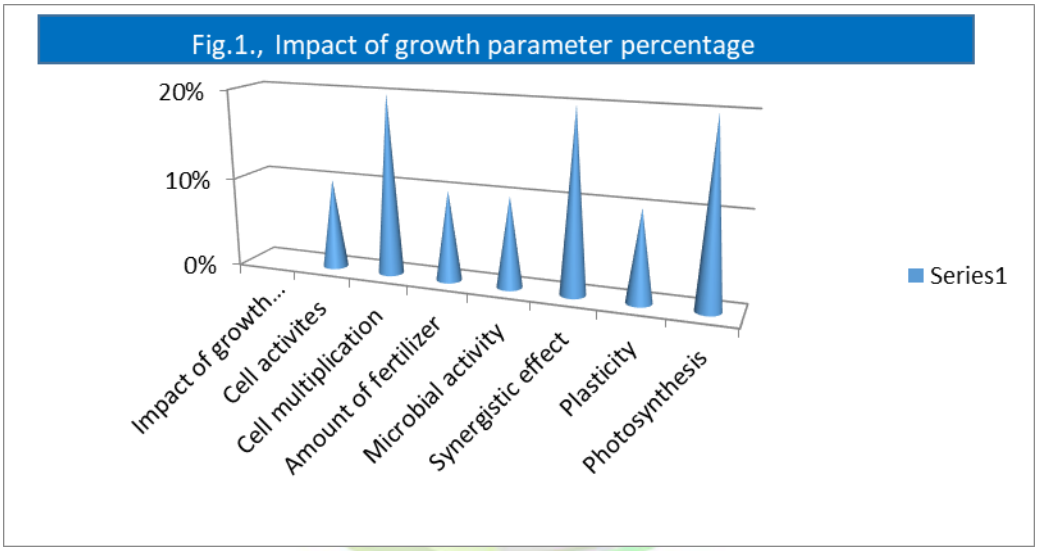
Leaf area index (LAI)

Leaf area Index (LAI), an important growth factor of blackgram crop and data regarding LAI are shown in Humic acid treatment adapted in blackgram crop has significant effect on its LAI in both the year of experiments. It is clear that in comparison to other treatments the highest LAI (3.38 and 3.52 respectively in 2018 and 2019) was obtained from T_9 treatment. However, both the control (T_1 and T_2) treatment gives the lower value of LAI in both the year of experiments. The combine effect of HA and compost improved the LAI significantly. Most of the growth stages seed priming was at par with the control and the two control treatments (T_1 and T_2) were at par in both the years. Higher LAI values might be due to adequate supply of nitrogen that had produced larger leaves and reflected in more photosynthetic area coupled with the increased growth rate, respiration rate and metabolic activity due to humic substances (Saravanan *et al*., 1989).

Dry aerial biomass

Dry aerial biomass is one of the most important parameters and has a marked influenced on final growth realization of a crop. The mean dry aerial biomass of blackgram as influenced by different treatments of humic acid , Soil application of HA with or without compost had a profound effect in increasing the total aerial dry matter production over control and treatments

receiving N-P-K and seed priming (T_2). T_9 treatment recorded the highest value of dry aerial biomass in both the years of experiments where HA at 2 kg ha^{-1} was applied in soil along with farm compost at 10t ha^{-1}; the second highest value of dry aerial biomass was recorded in treatment T_8 where HA at 1 kg ha^{-1} was applied in soil along with farm compost at 10 t ha^{-1} and the lowest value was recorded in control treatment (T_1). The revealed that foliar application of HA significantly increased the dry aerial biomass over in both 2018 and 2019 and on an average, there was an increase of 37.86 and 37.18% over control in 2018 and 2019, respectively. The results of this experiment are similar with the finding of Khazaie *et al*., (2011). HA was capable of increasing the total amount of dry weight in soybean, peanut and clover plants (Tan *et al*., 1983).



Conclusion

Summary and Conclusion is as follows the growth parameters of black gram i.e. plant height, leaves number $plant^{-1}$, branches number $plant^{-1}$ was significantly varied with different treatments. It was also reported that all growth parameters significantly increased with the increasing doses 100% with RDF. Amongst all the treatments 100% of RDF gave maximum plant growth as compared to other treatments at different growth intervals, While, it was at par with application of 75% RDF + 25% vermi-compost. It was also reported that during these studies the recommended dosage of fertilizer gave significantly higher in plant height (T_1 100% RDF at harvest 34.47 cm), leaves number $plant^{-1}$ 26.60 at 60 DAS and branch number $plant^{-1}$ 14.00 over control when compared to other treatments.

HA is one of the active major present in organic fertilizer as well as soil and organic matter. This study established that application of humic acids increased overall crop performance and productivity of blackgram. Among the different methods, soil application of humic acid was found to be the best, particularly when applied with compost. Therefore, soil application of humic acid @ 2 kg ha^{-1} + 10 t compost ha^{-1} (T_9) might be the best option for increasing productivity and quality of blackgram. It was concluded that with the application of GA3 45 ppm along with 50 ppm Salicylic acid at 15 & 40 DAS T_{10}, has performs positively and improves growth parameters.

From the Meta analysis growth is influenced (Fig.1.,) by cell activities, cell multiplication, amount of fertilizer, Microbial activity, synergistic effect, plasticity and photosynthesis. Here 20% level influenced and compared to these each three factors cell multiplication, Synergistic effect and photosynthesis. Other factors each one 10% impact to provide for growth parameters development in blackgram .

Reference

1. Saini, R., and Jaiwal, P. K. 2002. Age, position in mother seedling, orientation, and polarity of the epicotyl segments of blackgram (Vigna mungo L. Hepper) determines its morphogenic response. Plant Science. 163(1): 101-109.

2. Selvakumar, G., Reetha, S. and Thamizhiniyan, P. 2012. Response of biofertilizers on growth, yield attributes and associated protein profiling changes of blackgram (Vigna mungo L. Hepper). World Applied Sciences Journal. 16(10): 1368-1374.

3. Anonymous, 2018. Directorate of Economics and Statistics (DES): Based on 3rd Advance Estimates for 2017-18. Commodity Profile for Pulses-July, 2018.

4. Singh, R. K., Dawson, J., and Srivastava, N. 2017. Effect of sources of nutrient on growth and yield of blackgram (Vigna mungo L.) Varieties in NEPZ of India. Journal of Pharmacognosy and Phytochemistry. 6(4): 1064-1066.

5. Kokani, J. M., Shah, K. A., Tandel, B. M. and Nayakan, P. 2014. Growth, yield attributes and yield of summer Black Gram (Vigna mungo L.) as influenced by FYM, phosphorus and sulphur. The Ecoscan. Special Issue. VI: 429-433.

6. Fatima Anaya, Rachid Fghire, Said Wahbi, Kenza Loutfi. Influence of salicylic acid on seed germination of *Vicia faba* L. under salt stress. Journal of the Saudi Society of Agricultural Sciences. 2015; 17(1):1-8.

7. Ferdowsi noor, Feroza Hossain, Umme ara. Effects of gibberellic acid (GA3) on growth and yield paramaters of French bean (*Phaseolus vulgaris* L.). Journal of Asian. Soc. Bangladesh, Sciences. 2017;43(1):49-60.

8. Vekaria GB, Rakholiya KD, Vora VD, Patel JT, Sutaria GS, Vekaria PD. Response of Sesame (*Sesamum indicum* L.) to Growth Regulator under Dry Farming Condition. International Journal of Current Microbiology and Applied Sciences. 2017;6(3):1113-1120.

9. Neelambari, Chetanaben Mandavia, Sree Ganesh S. Curative Effect of Ascorbic Acid and Gibberellic Acid on Wheat (*Triticum astivum* L.) Metabolism under Salinity Stress. International Journal of Current Microbiology and Applied Sciences. 2018;7(1):522-533.

10. Nikita Nehal, Ah Khan, Nitish Sharma, Sanjay Kumar Tripathi, Mayanker Sing. Role of GA3, SA and ABA on growth and yield of Indian mustard [*Brassica juncea* (L.) Czern. & Coss.] under rainfed condition. Journal of Pharmacognosy and Phytochemistry. 2018;2:199-203.

11. Pradip Kumar Saini, Yadav RK, Mayank Pratap. Effect of Foliar Application of GA3, on Yield and Quality of Indian Mustard [*Brassica juncea* (L.) Czern. & Coss.] Under Sodic Soil. International Journal of Current Microbiology and Applied Sciences. 2017;6(12):4156-4159.

12. Solanki Mital V, Trivedi Sandhya K, Kandoliya UK, Golakiya BA. Effect of exogenous application of salicylic acid on antioxidative enzymes in black gram (*Vigna mungo* (L.) Hepper) irrigated with saline water. International Journal of Chemical Studies. 2018;6(4): 2107- 2116.

13. Reham Dawar, MD Giri, Ajit Kumar Meena, Gopal Patidar, Sandeep Rathod. Effect of foliar application of gibberellic acid on growth, yield and economic of black gram. Journal of Pharmacognosy and Phytochemistry. 2020;9(4):3128– 3190.

14. Lavanya, S.A., Vanniarajan, C. and Souframanien, J. (2022). Study of chlorophyll and macro mutations induced by physical mutagens in blackgram [*Vigna mungo* (L.) Hepper]. Legume Research. 45(3): 311-314. doi: 10.18805/LR-4200.

15. Patial, R., Mittal, R.K., Sood, V.K. and Ahmed, S. (2022). Studies on combining ability for seed yield and its related traits in blackgram [*Vigna mungo* (L.) Hepper]. Legume Research. 45(3): 292-298.

16. Govindasamy, R. (2002). Scope on the Use of Lignite Derived Humic Subtances for Sustainable Crop Producton. In: National Seminar on Recent Trends on the Use of Humic Subtances for Sustainable Agriculture, Annamalai University, Tamil Nadu.

17. Schnitzer, M. (1968). Reaction between fulvic acid, a soil hunic compound and inorganic soil constituents. Soil Science Society of America Journal. 33: 75-81.

18. Nithila, S., Annadurai, K., Jeyakumar, P., Puppala, N. and Angadi, S. (2013). Humic acid on growth, yield and biochemical properties of field crops with particular reference to peanut: A review. American International Journal of Research in Science, Technology, Engineering and Mathematics. 4(2): 128-132.

19. Singh, V. K., Sharma, B. B. and Sahu, J. P. 2008. Effect of organic and inorganic sources of nutrients on black gram productivity. Journal of Food Legumes. 21(3): 173-174.

20. Singaravel, R., Balasubramanian, N.T. and Govindasamy, R. (1993). Effect of humic acid on sesame (*Sesamum indicum*) growth and yield under two nitrogen levels. Indian Journal of Agronomy. 38(1): 147-149.

21. Prasad, M. and Prasad, R. (1994). Effect of some plant growth regulators in cotton. Indian J. Plant Physiol. 37: 109-110.

22. Rathore, R. S., Singh, R. P., and Nawange, D. D. 2010. Effect of land configuration, seed rates and fertilizer doses on growth and yield of black gram [Vigna mungo (L.) Hepper]. Legume Research: An International Journal. 33(4): 274-278.

23. Fashina, A. S., Olatunji, K. A., and Alasiri, K. O. 2002. Effect of different plant populations and poultry manure on the Int.J.Curr.Microbiol.App.Sci (2019) 8(6): 2045-2053 2052 yield of Ugu (Telfairia occidentalis) in Lagos State, Nigeria. In Proceedings of the Annual Conference of Horticultural Society of Nigeria (HORTSON), pp. 14- 17.

24. Singh, G., Ram, H., Sekhon, H. S., Aggarwal, N., Kumar, M., Kaur, P., and Sarma, P. 2011. Effect of nitrogen and phosphorus application on productivity of summer mungbean sown after wheat. Journal of Food Legumes. 24(4): 327-329.

25. Vadgave, S. M. 2010. Studies on Integrated Nutrient Management on Seed Yield, Int.J.Curr.Microbiol.App.Sci (2019) 8(6): 2045-2053 2053 Quality and Storability in Greengram [Vigna radiate (L.) Wilczek] (Doctoral dissertation, UAS, Dharwad).

26. Reddy, A., Babu, J. S., Reddy, M., Khan, M., and Rao, M. M. 2011. Integrated nutrient management in pigeonpea (Cajanuscajana). International Journal of Applied Biology and Pharmaceutical Technology. 2(2): 467-470.

27. Saravanan, A., Govindasamy, R. and Chandrasekaran, S. (1989). Effect of Humic Acid on the Yield and Composition of Sugarcane (Saccharum officinarum L.) Variety CoC 8506. In:

Proceedings of National Seminar on Humic acid in Agriculture. Annamalai University, Tamil Nadu. pp. 235-242.

28. Khazaie, H.R., Rezaie, E.E. and Bannayan, M. (2011). Application times and concentration of humic acid impact on aboveground biomass and oil production of hyssop (*Hyssopus officinalis*). Journal of Medicinal Plants Research. 5(20): 5148-5154.

29. Tan, K.H. and Tantiwiramanond, D. (1983). Effect of humic acids on nodulation and dry matter production of soybean, peanut and clover. Soil Science Society of America Journal. 47: 1121-1124.

Volume: 06 Issue No: 09

TINY MICROBES, BIG HARVESTS: THE SCIENCE OF BIOFERTILIZERS

Article ID: AG-VO6-I09-141

Pearl Saharan

Department of Microbiology

Chaudhary Charan Singh Haryana Agricultural University, Hisar 125 004, India

Abstract

Beneath every thriving crop lies an invisible biological world. Millions of microbes inhabit the soil surrounding plant roots, forming intricate communities which influence disease resistance , nutrient availability, plant development, and soil fertility. Although these organisms are microscopic, their contribution to agriculture can be enormous. This is the scientific foundation of biofertilizers, preparations containing beneficial microbes which improve plant nutrition and stimulate crop growth through biological processes. Rather than simply supplying nutrients in a readily available chemical form, biofertilizers also harness the natural metabolic capabilities of microbes to make nutrients accessible to plants and improve the biological functioning of the soil. For a country such as India, where agricultural productivity must be balanced with soil conservation, water security and environmental sustainability, biofertilizers represent an important component of modern agricultural microbiology.

Keywords: *Azotobacter*, Biofertilizers, Bioformulation, Biological Nitrogen Fixation, Cyanobacteria, Metagenomics, Microbial Consortia, Plant Growth Promoting Microbes, Rhizosphere, Sustainable Agriculture

What Are Biofertilizers?

Biofertilizers are formulations containing living or dormant microbes that, when applied to seeds, plants or soil, enhance nutrient availability and promote plant growth. Important groups include *Rhizobium*, *Azotobacter*, *Azospirillum*, cyanobacteria, phosphate solubilizing microbes, K mobilizing microbes and mycorrhizal fungi. Their importance arises from the remarkable biochemical activities of these microbes. Some fix atmospheric nitrogen, some release

phosphorus from insoluble compounds, while others produce substances which influence root architecture and plant development. Biofertilizers should not be viewed simply as biological substitutes for chemical fertilizers. They are better understood as microbial technologies that strengthen the biological relationship between soil and plant.

Nitrogen Fixation: Turning Atmospheric Nitrogen into Plant Nutrition

Nitrogen is indispensable for plant growth as it forms an integral component of amino acids, proteins, nucleic acids, chlorophyll and several other cellular molecules. Although the atmosphere contains approximately 78% nitrogen, plants cannot directly utilise atmospheric nitrogen gas. This is where nitrogen fixing microbes become important. *Rhizobium* establishes a remarkable symbiotic relationship with leguminous plants. The bacteria colonise root tissues and participate in the formation of specialised structures called root nodules. Within these nodules, atmospheric nitrogen is converted into biologically useful forms through the enzyme nitrogenase. Free living microbes such as *Azotobacter* can also contribute to biological nitrogen fixation, while *Azospirillum* is particularly associated with grasses and cereals. Cyanobacteria such as *Anabaena* and *Nostoc* contribute to nitrogen enrichment, particularly in aquatic and rice based agricultural ecosystems. The significance of biological nitrogen fixation extends beyond nutrient supply. It represents a natural biological process through which atmospheric nitrogen enters agricultural ecosystems.

Phosphorus Solubilization: Unlocking a Hidden Nutrient Reserve

P is essential for energy transfer, nucleic acid synthesis, membrane structure and plant development. A considerable proportion of soil P exists in forms that plants cannot readily absorb. Phosphate solubilizing microbes provide a biological solution. Certain bacteria and fungi release organic acids, enzymes and other metabolites that transform poorly available P compounds into forms that plants can utilise. The process illustrates an important principle of agricultural microbiology: soil fertility depends not only on how much nutrient is present, but also on how biologically accessible that nutrient is. Microbes act as biochemical mediators between soil minerals and plant roots.

Microbial Factories Around Plant Roots

The region immediately surrounding a plant root is known as the rhizosphere. It is one of the most biologically active zones in soil. Roots release compounds such as sugars, amino acids and organic acids into the surrounding soil. The substances influence microbial colonisation and

create a dynamic environment where plants and microbes continuously interact. Plant growth promoting microbes produce compounds such as indole acetic acid, gibberellin like substances and cytokinins, which influence root development and nutrient acquisition. Some microbes also produce siderophores that bind iron, enzymes that modify organic compounds and metabolites that can suppress certain soil borne pathogens. Biofertilizers can influence plants through several interconnected mechanisms rather than through nutrient supply alone.

From Laboratory Culture to Agricultural Field

Producing an effective biofertilizer involves much more than growing a microbe in a flask. A suitable microbial strain must first be isolated, identified and screened for desirable attributes. Scientists examine properties such as biological nitrogen fixation, phosphate solubilization, plant growth promotion and stress tolerance. The selected organism is then multiplied under controlled conditions using respective culture medium. The microbial culture is subsequently incorporated into a suitable carrier or developed into a formulation that protects the microbes during storage and application. Quality control is crucial. A successful formulation must contain an adequate population of viable microbes and remain stable for an appropriate period. Application methods may include bacterization, seedling root treatment, soil application and direct application around the rhizosphere.

Biofertilizers and Sustainable Agriculture

The increasing dependence on synthetic fertilizers has contributed enormously to agricultural productivity, but inefficient or excessive nutrient application can contribute to nutrient losses, water contamination, soil degradation and greenhouse gas emissions. Biofertilizers offer a biological approach to improving nutrient use efficiency. Biofertilizers should not be portrayed as a universal replacement for chemical fertilizers. Their effectiveness depends on the microbial strain, crop genotype, soil characteristics, temp, moisture, agricultural practices and interactions with the indigenous soil microbiome. The most realistic future lies in integrated nutrient management, where microbial technologies complement appropriate mineral and organic nutrient sources.

The Rise of Microbial Consortia

One microbe may perform one function exceptionally well, but agriculture is an ecosystem rather than a single biochemical reaction. This has encouraged researchers to investigate microbial consortia, combinations of beneficial microbes designed to perform

complementary functions. One microbe may improve nitrogen availability while another enhances phosphorus solubilization and another supports root development or stress tolerance. Such combinations represent an important direction in modern agricultural microbiology as they attempt to reproduce some of the functional diversity naturally found within healthy plant microbiomes.

Biofertilizers Enter the Genomic Era

The next generation of biofertilizer research is becoming increasingly sophisticated. Traditional microbiology often focused on culturing individual microbes. Modern researchers can now investigate entire microbial communities using metagenomics, transcriptomics and other omics technologies. Metagenomic approaches can reveal which microbes are present in agricultural soils and which functional genes may contribute to nutrient cycling and plant growth. This opens an exciting possibility. Instead of selecting beneficial microbes only through conventional screening, scientists can increasingly identify microbes according to their genetic characteristics and ecological functions.

Nano Biofertilizers: A New Frontier

Another emerging area is the intersection of microbiology and nanotechnology. Researchers are investigating whether nanomaterials can be incorporated into microbial formulations to improve nutrient delivery, microbial survival or plant responses. This emerging field is particularly interesting as it combines microbial biotechnology, nanotechnology and plant physiology. Technological advancement must be accompanied by careful evaluation of microbial compatibility, plant responses, environmental persistence and ecological safety.

The Climate Challenge

Agriculture is increasingly exposed to drought, heat, salinity, flooding and other environmental stresses. Beneficial microbes help plants respond to these challenges by influencing root development, nutrient acquisition, antioxidant systems and stress signalling. The future of biofertilizers may therefore extend beyond the simple question of supplying nitrogen or phosphorus. The larger objective is to develop microbial systems that help crops maintain productivity under environmental uncertainty.

Why Field Performance Still Matters

One of the greatest challenges facing biofertilizer technology is the difference between lab performance and field performance. A microbe which performs exceptionally well under

controlled lab conditions may behave differently when introduced into agricultural soil containing thousands of competing microbial sp. Temp, soil pH, moisture, nutrient availability, crop variety and agricultural practices can all influence microbial establishment. The future requires not merely better microbes, but better bioinoculants, better field testing and better understanding of soil microbial ecology.

Indian Agricultural Perspective

For Indian agriculture, biofertilizers have particular relevance because soil fertility, input efficiency and environmental sustainability are closely interconnected. Agricultural universities and research institutions play an important role in developing, testing and transferring microbial technologies to farmers. The integration of microbiology with agronomy, soil science, biotechnology and agricultural extension can help transform lab discoveries into practical technologies suitable for Indian farming systems.

Conclusion

The smallest organisms in agricultural ecosystems may hold some of the biggest possibilities for the future of food production. Biofertilizers demonstrate how microbiology can transform invisible biological processes into practical agricultural technologies. Nitrogen fixing bacteria, phosphate solubilizing microbes, cyanobacteria, mycorrhizal fungi and other plant growth promoting microbes influence nutrient cycling, soil fertility and plant development. The future of biofertilizers will not be determined simply by discovering another beneficial microbe. It will depend on understanding the plant microbiome, microbial ecology, formulation science, genomics, climate interactions and field level performance as interconnected components of one biological system. From traditional *Rhizobium* inoculation to microbial consortia, metagenomics and nano biofertilizer research, agriculture is moving toward a more biologically informed future. The next agricultural revolution may not always be visible above the soil. It may begin beneath our feet, where microscopic organisms are quietly helping plants turn biological potential into healthier, more efficient and sustainable harvests.

References

Adesemoye, A. O., Torbert, H. A. and Kloepper, J. W. Plant growth promoting rhizobacteria allow reduced application rates of chemical fertilizers. *Microbial Ecology*, 58, 921 to 929.

Bhattacharyya, P. N. and Jha, D. K. Plant growth promoting rhizobacteria: Emergence in agriculture. World Journal of Microbiology and Biotechnology, 28, 1327 to 1350.

Dhanda, D., Saharan, B. S., Kumar, D., Kamboj, A., Goyal, C., & Duhan, J. S. (2026). Advances in Agriculture-Based Technology for Sustainable Agriculture and Environment. Agriculture (Pol'nohospodárstvo), 72(1), 1-16.

Glick, B. R. Plant growth promoting bacteria: Mechanisms and applications. Scientifica, 2012, Article ID 963401.

Gupta, A., Saharan, B. S., Sadh, P. K., & Duhan, J. S. (2024). Green to green: harnessing bio-fertilizers for sustainable pulse production and food security. Discover Plants, 1(1), 73.

Kamal, N., & Saharan, B. S. (2025). Evaluation of plant growth-promoting traits in Azotobacter and Trichoderma strains isolated from natural farms in India. *Vegetos*, 1-15.

Kumar, A., Saharan, B. S., Parshad, J., Gera, R., Choudhary, J., & Yadav, R. (2024). Revolutionizing Indian agriculture: the imperative of advanced biofertilizer technologies for sustainability. *Discover Agriculture*, 2(1), 24.

Madigan, M. T., Bender, K. S., Buckley, D. H., Sattley, W. M. and Stahl, D. A. Brock Biology of Microorganisms. Pearson.

Pandey, K., & Saharan, B. S. (2025). Potassium-solubilizing endophytes: mechanisms and applications in enhancing sustainable agriculture and plant resilience. Symbiosis, 95(3), 291-305.

Pelczar, M. J., Chan, E. C. S. and Krieg, N. R. Microbiology: An Application Based Approach. McGraw Hill.

Prescott, L. M., Harley, J. P. and Klein, D. A. Microbiology. McGraw Hill Education.

Saharan, B. S., & Nehra, V. (2011). Plant growth promoting rhizobacteria: a critical review. Life Sci Med Res, 21(1), 30.

Subba Rao, N. S. Biofertilizers in Agriculture and Forestry. Oxford and IBH Publishing.

Teja, A. P. S. N., & Saharan, B. S. (2025). Endophytic potassium-solubilizing microbes: A sustainable approach to enhancing crop nutrition and productivity. In Metabolic Sustainability of Endophytes: Current Status, Challenges and Potential (pp. 37-53). Singapore: Springer Nature Singapore.

Vessey, J. K. Plant growth promoting rhizobacteria as biofertilizers. Plant and Soil, 255, 571 to 586.

AgriGate Editorial Team



September 2026 |Vol. 06 |Issue No 09

Founder & Managing Director : **Mrs. Priya V**

Editor-In-Chief : **Dr. R. Shiv Ramakrishnan**

International Advisor : **Prof. Chittaranjan Kole**

Executive Editors : Dr. Sivalingam Elayabalan
Dr. Muthusamy Ramakrishnan

Editorial Manager : Dr. R. Vinoth

Editorial Advisor : Dr. G. Selvakumar

Senior Editor : Dr. K. Subrahmaniyan
Dr. N. Venkatesa Palanichamy
Dr. R. Kalaiyarasi
Dr. M. Baskar
Dr. A. Malaisamy

Editors : Dr. L. Pugalendi
Dr. M. L. Dotaniya
Dr. L. Allwin
Dr. A. Thanga Hemavathy
Dr. S. Rathika
Dr. S. Srividhya
Dr. M. Dhandapani
Dr. M. Vengateswari
Dr. G. Sathish
Dr. P. Preetha
Dr. C. Sellaperumal
Dr. S. Kavitha
Dr. R. Pravallika sree
Dr. P. Reddy Priya
Dr. M. Paramasivan
Dr. S. Murali
Dr. S. Subash
Dr. Andukuri Raj Shravanthi
Dr. K. Elanchezhyan
Dr. C. Inbaraj

Media Managers Mr. R.C. Karthikeyan
Mr. V. Kabilraj

AgriGate

GROW WITH EVERY PAGE!

An International Multidisciplinary Monthly e-Magazine

Inviting Popular Articles for October Issue 2026

Dear Authors,

We are inviting Technical Article, Popular Article, Farmer Success Stories, and Short Communications from various disciplines of Agriculture and Allied Sciences in English Language.

- Agriculture & Horticulture
- Agribusiness Management
- Agricultural Engineering and Precision Farming
- Agronomy and Agricultural meteorology
- Agrl. Extension and Agrl. Economics
- Bio-Sciences / Life-Sciences
- Biotechnology & Bio-chemistry
- Environmental Science & Forestry
- Fisheries & Animal Sciences
- Food & Dairy Technology
- Genetics & Plant Breeding
- Nematology & Nano-Technology
- Organic Farming and Sericulture
- Plant Pathology & Entomology
- Seed Science & Technology
- Soil Science

Send your articles to agrigatepublish@gmail.com

(Deadline for submission of articles – 20th October, 2026)

"Limit the Articles to 6-7 Pages"

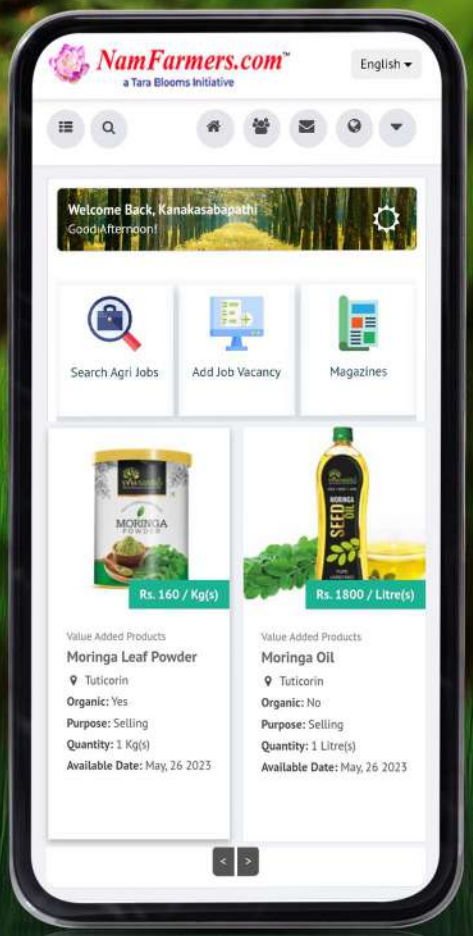
NamFarmers.com™

a Tara Blooms Initiative

Open gate for

AGRO PRODUCTS

Let's market globally



GET IT ON Google Play

Available on the App Store

T&Cs Apply

+91 770 8222 822 support@namfarmers.com www.namfarmers.com