OCTOBER 2026 |VOLUME 06| ISSUE 10

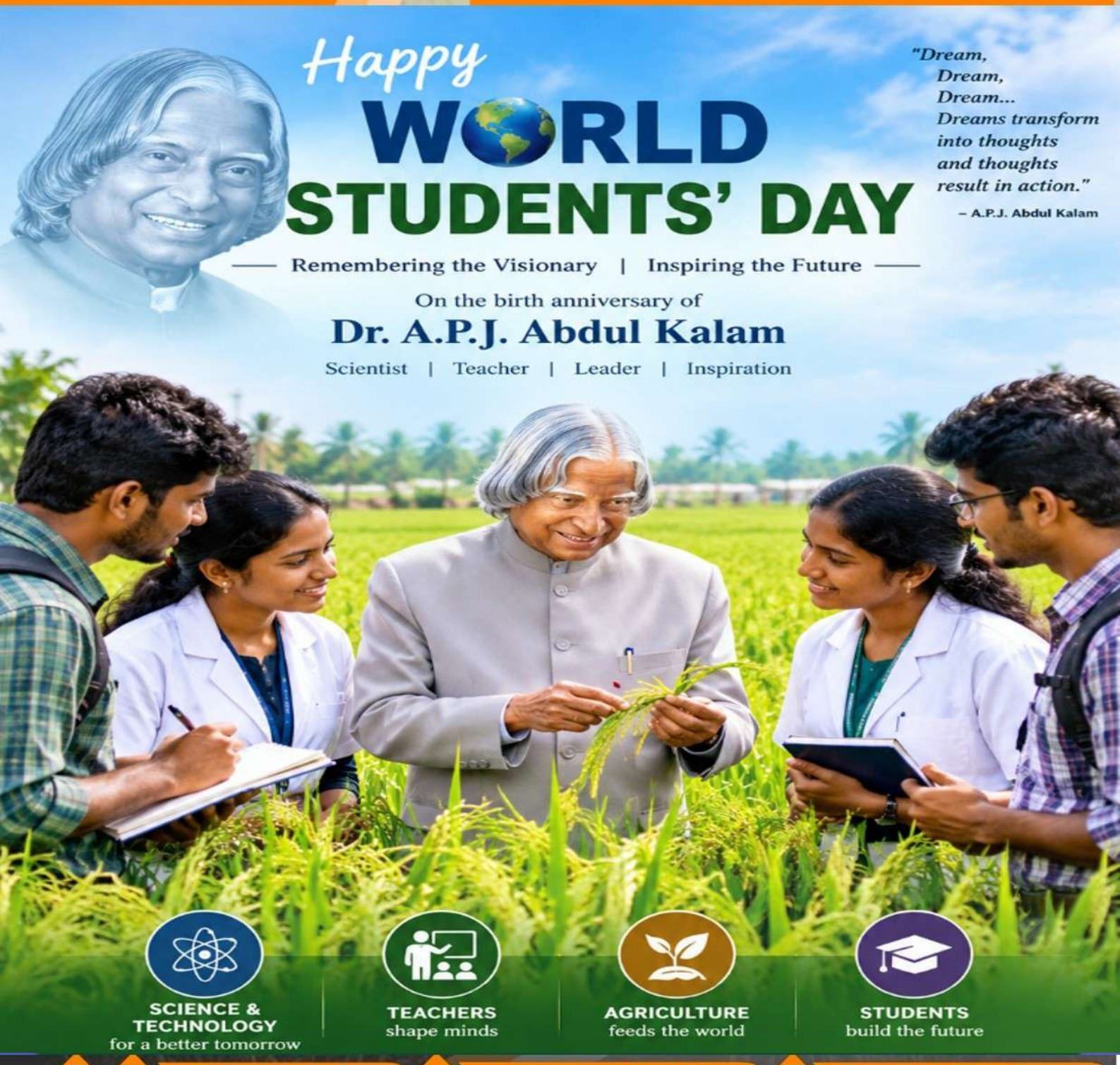
MSME Reg No:UDYAM-TN-05-0080141

AgriGate

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

GROW WITH EVERY PAGE!

An International Multidisciplinary Monthly e-Magazine



From the Desk of Editor-in-chief



October 2026| Vol. 06 |Issue No. 10

I would like to introduce the launch of **"AgriGate - An International Multidisciplinary Monthly e-Magazine Volume 06 Issue No. 10 – October 2026"** with immense pleasure our team is privileged to dedicate this issue to the Agricultural Students and scholars. **World Students' Day** is observed on 15 October annually to mark the birth anniversary of A.P.J. Abdul Kalam. This day honours and pays respect to him and his efforts in the field of science and technology and also the role of the teacher that he played throughout his scientific and political careers. **World Teachers' Day** is celebrated on 5 October every year in the whole world. Recommendation sets benchmarks regarding the rights and responsibilities of teachers, education, recruitment, employment, etc.

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.

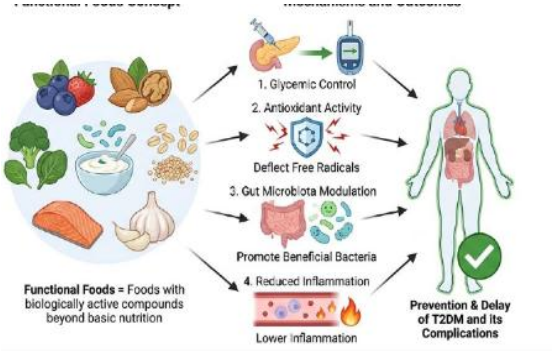


Dr R Shiv Ramakrishnan
Editor-in-chief
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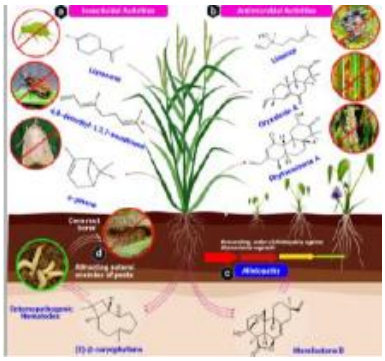
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AS RABI SOWING BEGINS, CROPLIFE INDIA ISSUES FOUR-POINT ADVISORY

Press Release

New Delhi, 13 October 2026: CropLife India, the apex association of leading R&D-driven crop science companies, has issued a four-point advisory for the Rabi 2026-27 season, spanning seed, sowing, scouting and sourcing, in the wake of the weakest monsoon since 2015. It outlines how the judicious use of crop protection products can help farmers protect their crops and manage input costs without compromising yields.

With member companies representing for about 70% of the Indian crop protection market, CropLife India works with farmers, the state agriculture universities and the Government on product stewardship and the responsible use of crop protection products. The advisory reflects established agronomic practice and is intended to help farmers make informed decisions at every stage of the Rabi crop.

On seed, the advisory identifies treatment before sowing as the most cost-effective safeguard against seed- and soil-borne diseases, including smut in wheat, which is aggravated by cool, moist conditions, and wilt and dry root rot in chickpea, which are aggravated by moisture stress and heat. On sowing, it recommends termite treatment only in fields, with a history of infestation and where soil moisture is adequate for the treatment to be effective, and notes that mustard sown in the second fortnight of October, where moisture permits, faces lower aphid pressure at flowering. On scouting, it advises that applications be guided by regular field monitoring rather than a fixed calendar; wheat aphids, for instance, warrant control only once they exceed 10-15 per tiller. Unusual pest or disease outbreaks may be reported through the National Pest Surveillance System or the nearest Krishi Vigyan Kendra. On sourcing, farmers are advised to purchase only from authorised dealers against a proper bill, and also to verify the expiry date before use.

The association also cautioned that a difficult season increases the risk of illicit products reaching farmers and reiterated its call for firm enforcement against unauthorised trade,

including explicit regulation of online sales supported by licence verification and product traceability.



"The weakest monsoon in over a decade has altered the starting conditions for Rabi. Uneven soil moisture influences how crops establish, how pests and diseases behave, and how effectively inputs perform, which means the decisions farmers take in the coming weeks will shape the entire season. Farmers should reach out to the nearest agricultural research stations, KVKs or agriculture department officials for any support or guidance. This advisory is intended to help them make each of those decisions count, protecting the crop at its most cost-effective stage, applying products judiciously, safely and sourcing only genuine inputs. In a season such as this, precision is what safeguards both the harvest and the farmer's investment," said **Durgesh Chandra, Secretary-General, CropLife India**.

According to the India Meteorological Department, the southwest monsoon ended the season at 87% of its long-period average, with rainfall in the southern and eastern regions at 76% and 74% respectively.

The Centre's revised minimum support prices for Rabi crops include increases of Rs 675 per quintal for safflower, Rs 413 for rapeseed and mustard, Rs 390 for lentil, Rs 136 for barley, Rs 83 for gram and Rs 25 for wheat, with the steeper increases for oilseeds and lentil reflecting the policy emphasis on crop diversification. The Centre has also indicated that El Niño could bring excess soil moisture to some rainfed areas, and prolonged moisture stress to others, the very conditions the advisory seeks to help farmers manage.

About CropLife India

CropLife India is committed to advancing sustainable agriculture and it is an association of 17 R&D driven member companies in crop protection. We jointly represent ~ 70% of the market and are responsible for 95% of the molecules introduced in the country. Our member companies have annual global R & D spend of 6 billion USD and are firmly committed to engaging with the farming community to enable Safe, Secure Food Supply.



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ESCORTS KUBOTA ANNOUNCES PRICE REVISION ACROSS KUBOTA, FARMTRAC AND POWERTRAC TRACTORS AMID RISING INPUT COSTS

Press Release

Faridabad, 30th October, 2026: Escorts Kubota Limited (EKL), one of India's leading agri-machinery and construction equipment manufacturers, today announced a price increase across its Kubota, Farmtrac and Powertrac tractor ranges. The price revision will come into effect in November 2026 after the festive season.

Revised prices across the product range will come into effect in November 2026, after the festive season

The price revision is driven by the continued rise in input costs, including raw materials, energy, logistics and manufacturing expenses, mainly impacted by inflationary trends and ongoing geopolitical uncertainties.

Over the past several months, EKL has undertaken a range of cost optimization and operational efficiency initiatives to mitigate the impact of rising costs. The company has also absorbed a substantial portion of these increases. However, with input costs continuing to remain elevated, the price revision has become necessary to partially mitigate higher manufacturing and operating expenses.

The price revision will come into effect in November 2026 after the festive season and will vary across models, variants and geographies within the Kubota, Farmtrac and Powertrac portfolios. Revised prices will be available through authorised dealerships.

Manish Sharma, President – Agri Business, Escorts Kubota Limited, said, *"We have made every effort to minimize the impact of rising input costs on our customers. This measured revision enables us to sustain our commitment to quality, innovation and customer value. We remain focused on delivering reliable, technology-led solutions through our Farmtrac, Powertrac and Kubota brands to support the productivity and profitability of Indian farmers."*

EKL has continued to expand its tractor offerings through launches including the Farmtrac PROMAXX series, Powertrac Shaurya series and expanded Digitrac range, alongside Kubota's NeoStar and MU series. These additions, supported by continued dealer network expansion,

reflect the company's focus on providing farmers with a wider choice of reliable, application-specific tractors suited to diverse agricultural needs.

About Escorts Kubota Limited (EKL)

Escorts Kubota Limited (EKL) is a leading engineering conglomerate with over 80 years of expertise, dedicated to delivering top-tier solutions in agricultural and construction equipment that drive India's development. The company crafts cutting-edge, dependable products, including its renowned tractor family—Kubota, Farmtrac & Powertrac. It also offers specialized agricultural machineries and a strong lineup of construction equipment. Together, these solutions unite Indian ingenuity with Japanese precision for exceptional performance. Through an extensive dealer network, EKL ensures these advanced, reliable products reach customers across India and globally, upholding its legacy as a forward-thinking leader in transforming agriculture and infrastructure.

Learn more at www.escortskubota.com

Volume: 06 Issue No: 10

APPLICATION OF DRONE TECHNOLOGY IN HORTICULTURE

Article ID: AG-VO6-I10-01

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Abstract

In this ever-changing world, the tools and technologies applied for horticulture change from time to time. It is necessary to stay updated on these techniques so as to improve the productivity of a crop and to achieve maximum yield with minimal use of resources. One such tools is a Drone. The drones are being used for almost everything from sowing to plant protection in crop production. This helps farmers to reduce costs and obtain higher yields with minimal harm to environment. This chapter consists of a proper introduction of a drone, what are the advantages of using drone over traditional methods, technologies used for crop monitoring and soil assessment and other such terminology related to drones.

Keywords: Drones, Horticulture, Crop monitoring, Soil assessment, Water quality assessment.

What is a Drone?

A drone, commonly known as Unmanned Aerial Vehicle (UAV) is a flying robot. T can be remotely operated or can fly autonomously through software-controlled flight plans in their embedded system working in conjunction with onboard Sensors and Global Positioning System (GPS). Drones are used widely used in many areas such as traffic surveillance, cargo, first aid, agriculture, entertainment, hobby, security and surveillance as they provide many customizable solutions that combine practicality and speed.

Drones in Horticultural Sector:

Drones can be used for wide range of tasks in the horticulture sector, including crop mapping, soil analysis, irrigation and pest management. The key benefits of drones in horticulture sector can be listed as below

- Drones improve the efficiency of farm operations. They can cover large areas of land quickly and efficiently allowing farmers to gather data and monitor crops more effectively. The easy and continuous monitoring helps to identify issues early, leading to faster and more effective interventions.
- The crop data collected during the monitoring is analyzed to determine the status on crop growth and health attributes, allowing farmers to identify areas that require attention. This can help farmers to improve their crop yields and in turn increase the profits and thus the crop productivity.
- The identification of areas that require attention helps to reduce costs by reducing the target area for the usage of pesticides and other control strategies.
- The high-resolution images captured by the drones helps to identify the efficiency of the control strategies on the target area.

Technology used in agricultural and horticultural drones:

- **Low altitude remote sensing technology (LARS)-** The concept of acquiring earth surface images at a low altitude using unmanned aerial systems (UAS). It is promoted to monitor crop growth, crop stress and to predict crop yield.
- **Multispectral camera remote sensing imaging technology-** This technology uses Green, Red, Red-edge and Near Infrared wave bands to capture both visible and invisible images of crops and vegetation. Multispectral images allow the farmers to see beyond the naked eye and helps in evaluating soil productivity and analyzing plant health.

Sensors used in drones:

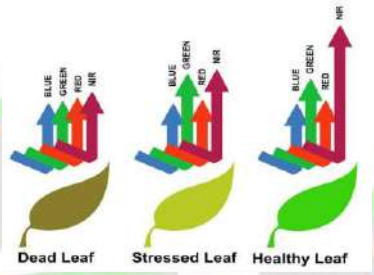
- **Multi-spectral-** Helps in the assessment of plant health and water quality, estimation of vegetation index and plant population.
- **Thermal-** Helps in detection of heat signature and livestock, surveillance and security, detection of water source and temperature.
- **LIDAR-** Surface variation detection and flood mapping, plant height measurements from plant canopy and ground below.

- **Hyperspectral-** Plant health measurement, water quality assessment, estimating vegetation index, spectral research and development, mineral and surface composition surveys.

Applications of drones in Agriculture and Horticulture:

Scouting/Monitoring Plant health

Drones equipped with special imaging equipment called Normalized Difference Vegetation Index (NDVI) use detailed color information to indicate plant health. This allows farmers to monitor crops as they grow so any problems can be dealt with fast enough to save the plants.



NDVI of leaves at different stages

Drones using regular cameras are also used to monitor crop health, density and coloration. Since these drones fly close to fields, drone imaging is capable of producing accurate image location. This means that after planting, areas with stand gaps can be spotted and replanted as needed and disease or pest problems can be detected and treated right away.

Monitoring field conditions

Drone field monitoring is also being used to monitor the health of soil and field conditions. Drones can provide accurate field mapping including elevation information that allow growers to find any irregularities in the field. Having information on field elevation is useful in determining drainage patterns and wet, dry spots which allow for more efficient watering techniques.



Drones for monitoring

Some drones also offer nitrogen level monitoring in soil using enhanced sensors. This allows for precise application of fertilizers, eliminating poor growing spots and improving soil health for years to come.

Planting and Seeding

One of the newer and less wide spread uses of drones in agriculture is for planting seeds. Automated drone seeders are mostly being used in forestry industries right now. Planting with drones means very hard to reach areas can be replanted without endangering workers.



Drone seeding

Spray Application

Drone sprayers are able to navigate very hard to reach areas, such as steep tea field at high elevations. They save workers from having to navigate fields with backpack sprayers, which can be hazardous to health. Drones deliver very fine spray that can be targeted to specific areas to maximize efficiency and save on chemical costs.



Drone spraying

Drone Pollination

Researchers in Netherlands and Japan are developing small drones that are capable of pollinating plants without damaging them. The next step is to create autonomous pollinating drones that will work and monitor crop health without constant instruction from operators.



Drone Pollinating

Drones Artificial Intelligence

Improving artificial intelligence in drones is important to be able to make them more useful to small farmers in developing nations. Current drone technologies are more effective in monitoring well known crops like corn which are planted in large monocultural patterns. Thus, more work is needed to be able to train AI systems to recognize fewer common crops and more diverse planting patterns.

Drone Irrigation

As climate change increasingly affects drought conditions, creating more efficient irrigation solutions is vital. Using microwave sensing, drones are able to capture very accurate soil health information including moisture levels without the plants getting in the way. This means water can be distributed in a field in the most efficient way in an effort to conserve resources.

Conclusion

With the ever changing and developing world, it is necessary to adapt new tools and technologies in horticultural sector so as to stay active and achieve efficiency in sustainable use of resources while improving the crop productivity. Drones are one such tool that enhances the crop yield, reduce cost of operation and saves time and resources. These drones are of different types and make and are adapted based on the requirement of the farm operation. For spraying, large drones with tank and sprayer equipment are used. These spraying drones are equipped with GPS for marking the accurate location details. The monitoring drones are small quadcopters equipped with cameras that capture the images of soil and vegetation to interpret the crop and soil health and water requirement and detection of any pests and diseases in early stage. And the drones are in early stages of development for pollination and irrigation. The complete development and adaptation of such technologies help in efficient monitoring of crop growth and soil health thus improving crop productivity and hence the improvement in gains for the farmers.

Volume: 06 Issue No: 10

SMART AND SUSTAINABLE FARMING IN FRUIT AND VEGETABLE CROPS

Article ID: AG-VO6-I10-02

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Introduction

With the increasing population in India, growing pressure on agricultural land and the limited availability of water resources, efficient and scientific water management in agriculture has become extremely important. Vegetable crops generally require frequent irrigation because their root systems are relatively shallow and maintaining adequate soil moisture is essential for obtaining good-quality production. Under such conditions, water conservation and micro-irrigation techniques, particularly **drip and sprinkler irrigation**, play an important role in saving water while improving productivity and quality.

A large proportion of agriculture in India depends on monsoon rainfall. Increasing population, urbanization, industrialization, excessive groundwater exploitation and climate change are continuously increasing pressure on water resources available for agriculture. On the other hand, fruits and vegetables are important sources of vitamins, minerals, fibre, antioxidants and other essential nutrients in our diet. Adequate water is required to maintain the productivity and quality of these crops; however, this does not mean that higher irrigation will always result in higher production. In fact, excessive irrigation can lead to wastage of water, nutrient leaching, deterioration of soil structure, waterlogging and increased disease problems. Therefore, the concept of **"more production with less water"** has become extremely important for fruit and vegetable production. This is the direction towards smart and sustainable farming.

Micro-Irrigation: The Basis of More Production with Less Water

Micro-irrigation is an irrigation system in which water is supplied directly to the root zone of crops in small quantities and at a controlled rate. It mainly includes drip irrigation, micro-

sprinkler and micro-sprinkler irrigation systems.

In drip irrigation, water is supplied through main pipes, sub-main pipes and lateral pipes through drippers/emitters placed close to the plants. Water is released into the soil drop by drop, allowing it to reach the root zone directly and maintaining moisture at a controlled level. A filtration system helps prevent sand, soil and other particles from entering the system, thereby reducing the possibility of clogging of drippers.

Drip irrigation is one of the most effective water-saving techniques for fruit and vegetable production. It can be effectively used in tomato, chilli, brinjal, cucumber, muskmelon, watermelon, okra, cauliflower and other vegetables, as well as in fruit crops such as papaya, banana, pomegranate, grape, mango, guava, citrus and others.

Benefits of Drip Irrigation in Vegetable Crops

1. **Water saving:** Water consumption can be considerably reduced compared with conventional irrigation methods.
2. **Increase in production:** Regular availability of moisture according to plant requirements improves plant growth and yield.
3. **Improvement in quality:** Fruit size, uniformity and marketable yield can be improved.
4. **Efficient use of fertilizers:** Application of soluble fertilizers along with irrigation water through the drip system is known as **fertigation**. This enables nutrients to reach the root zone directly.
5. **Weed management:** Since water is supplied mainly to the root zone of the crop, weed growth in unoccupied areas can be reduced.
6. **Conservation of soil and nutrients:** Surface runoff and unnecessary loss of nutrients can be reduced.
7. **Assistance in disease management:** Avoiding unnecessary wetting of leaves can reduce the risk of development of certain foliar diseases.
8. **Saving labour and energy:** Irrigation can be regulated and partially automated.

The quantity and interval of irrigation should be determined according to the crop, soil type, weather conditions, crop growth stage and local climate. By adopting water conservation, micro-irrigation, mulching, rainwater harvesting, soil-moisture conservation, efficient fertilizer use, weather-based irrigation and modern agricultural technologies, higher and better-quality

production can be obtained with less water. This can have a positive effect on farmers' production costs and income.

Micro-irrigation is not merely a water-saving technique; it is an important step towards sustainable and profitable vegetable production. Under changing climatic conditions, irregular rainfall, longer dry periods and rising temperatures have further increased the importance of water management. Therefore, water conservation, micro-irrigation, mulching and scientific crop management need to be adopted in an integrated manner.



Fig 1. Smart and Sustainable Crop Production through Mulching and Protected Cultivation in different vegetable and fruit crops

Nutrient Management through Fertigation

- The application of fertilizers along with drip irrigation is known as **fertigation**. In this system, water-soluble fertilizers are supplied to the root zone of plants through the irrigation system.
- In vegetables, nutrient requirements vary at different stages, including the early growth stage after transplanting, flowering, fruit setting and fruit development. In the conventional method, fertilizers are often applied to the field at one time, whereas in fertigation, the quantity and timing of nutrients can be adjusted according to the crop growth stage.

- Efficient use of nutrients can be improved by applying nitrogen, potassium and other essential nutrients in balanced and split doses. This enables plants to receive nutrients according to their requirements and can reduce the possibility of nutrient loss through leaching.
- Therefore, fertigation based on the principle of **"right quantity, right time and right place"** is an important component of smart farming. However, fertilizer quantities should be determined on the basis of soil testing, crop requirements and recommended agricultural practices.

Mulching: Maintaining Soil Moisture for a Longer Period

- Mulching is a simple and effective technique for water conservation. In this practice, the soil surface is covered with organic or inorganic materials. Plastic mulch, dry grass, crop residues, leaves and other suitable organic materials can be used as mulch.
- Mulching reduces evaporation from the soil surface and helps retain soil moisture for a longer period. In addition, it can help control weeds, moderate soil temperature and protect soil structure from the direct impact of raindrops. Organic mulch gradually decomposes and can contribute to increasing organic matter in the soil.
- When using plastic mulch, appropriate quality, thickness and type of mulch should be selected according to the crop. Safe collection and disposal of plastic mulch after use should also be ensured.

Rainwater Harvesting: Making Every Drop of Rain Reach the Field

- The distribution of rainfall in India is not uniform. In many regions, a large amount of rainfall occurs within a short period, and considerable quantities of water are lost as runoff. Under such conditions, rainwater harvesting is an important measure for water conservation.
- In fruit orchards, suitable water-harvesting structures can be created around plants to direct rainwater towards the root zone. In sloping areas, contour-based water conservation measures can help reduce surface runoff and soil erosion.
- Rainwater can be collected through field bunding, farm ponds, water-harvesting tanks, small reservoirs and farm ponds. This stored water can be used for supplementary irrigation when required.

Safe Reuse of Wastewater

- Along with water conservation, attention should also be given to the reuse of available water. Treated wastewater can be used for agriculture under suitable conditions. This can help reduce dependence on fresh water and improve the utilization of available water resources.
- Before reusing wastewater, its quality must be tested. Particularly in food crops, such water should be used for irrigation only when it meets the prescribed quality standards. Direct use of untreated or contaminated water can adversely affect soil, crops and human health.
- Depending on local conditions, treated water can be supplied in controlled quantities through drip or other suitable irrigation systems. In this way, water conservation, water reuse and micro-irrigation can be integrated to reduce pressure on limited water resources.

Importance of Soil Moisture Conservation

Along with reducing the amount of irrigation, it is also important to retain available water in the soil for a longer period. Maintaining adequate organic matter in the soil is useful for this purpose. Well-decomposed farmyard manure, compost, vermicompost and suitable organic residues can contribute to improving soil health. At the same time, avoiding excessive tillage, proper management of crop residues and maintaining soil structure are also important.

Nutrient management based on soil testing can reduce unnecessary fertilizer use and improve nutrient-use efficiency by crops.

Selection of Appropriate Crops and Varieties

For sustainable production with limited water, crops and varieties should be selected that are suitable for the local climate and soil, available irrigation resources, shorter production periods and adverse environmental conditions.

Before establishing fruit crops, it is beneficial to assess water availability, soil drainage capacity, rainfall pattern and local climatic conditions.

Weather-Based Irrigation Management in Vegetable and Fruit Crops

- Most vegetable crops have a relatively shorter duration than fruit crops; therefore, water management is particularly important in both.

- In crops such as tomato, chilli, brinjal, cucumber, bottle gourd, bitter gourd, okra, papaya, banana, pomegranate, grape, guava and mango, water requirements change according to plant age and growth stage.
- Adequate moisture is required during plant establishment, whereas in established plants, irrigation quantity and interval should be determined according to weather conditions and crop stage.
- Water deficiency during vegetable/fruit development can adversely affect yield and fruit quality, whereas excessive irrigation can increase the risk of waterlogging, root-related problems and nutrient losses.
- In smart farming, irrigation decisions should not be based solely on a calendar. Instead, irrigation intervals can be determined using simple approaches such as weather conditions, regular monitoring of soil moisture, expected rainfall and crop growth stage, thereby saving water.

Role of Digital Technology in Smart Farming

The use of digital technologies in agriculture is increasing rapidly. Mobile-based weather forecasts, irrigation advisories, soil-moisture sensors, automatic valves, remote monitoring and data-based agricultural decision-making can make water management more precise.

In large and commercial orchards, sensor-based automated irrigation systems can help supply water according to the actual requirements of plants.

The principle of **"only as much water as required"** will be important in the smart farming of the future.

Practical Suggestions for Farmers

For water-saving fruit and vegetable production, farmers can begin by adopting the following practices:

1. Get the field soil tested and manage nutrients according to the test results.
2. Select a drip irrigation system according to the crop requirements.
3. Ensure proper filtration and regular maintenance of the drip system.
4. Determine the timing and duration of irrigation according to crop growth stage and weather conditions.
5. Use mulching in the field.
6. Store rainwater in farm ponds or other suitable structures.

7. Maintain proper drainage facilities in the field.
8. Use fertilizers efficiently through fertigation.
9. Avoid unnecessary and excessive irrigation.
10. Select crops and varieties suitable for local conditions.
11. Use weather forecasts and agricultural advisories.
12. Regularly inspect drip lines, filters and emitters.
13. Properly utilize crop residues to increase organic matter in the soil.
14. Maintain records of irrigation and crop production so that better decisions can be taken in the following season.

Conclusion

Water is the foundation of agricultural production and plays an extremely important role in fruit and vegetable production. Considering the increasing challenges of climate change, declining water resources and growing agricultural requirements, it is essential to use available water precisely, scientifically, efficiently and in a controlled manner. Simply providing more water or adopting drip irrigation alone cannot guarantee water conservation and higher production. An **integrated water-management approach** is necessary.

Rainwater harvesting, drip or micro-irrigation, scientific fertigation, mulching, soil health and moisture conservation, weather-based irrigation, selection of suitable crops and varieties, and the integrated use of digital agricultural technologies can play an important role in improving the efficiency of water and nutrient use. By adopting these technologies according to local climate, soil, crop requirements and available water resources, higher, better-quality and profitable production can be achieved with less water.

Therefore, water conservation is not limited to any single technology; rather, it is a process of scientific and comprehensive improvement of the entire agricultural production system. Today, the need is not merely for **"higher production"**, but for **"higher production with limited resources, better quality, greater profitability and conservation of natural resources."** The effective integration of water conservation and micro-irrigation technologies can improve water-use efficiency, productivity and crop quality, while also contributing to increased farmers' income and making agriculture more sustainable and environmentally friendly.

Thus, if farmers adopt the principles of **"making every drop count, irrigating according to the requirements of each plant, and managing every field scientifically,"** fruit and vegetable production can be made more productive, profitable, sustainable and environmentally friendly despite limited water resources. This is an important step towards smart and sustainable agriculture and can serve as a foundation for water security and food security in the agriculture of the future.

Volume: 06 Issue No: 10

MINOR LEAFY VEGETABLES: NUTRITIONAL, MEDICINAL AND THERAPEUTIC POTENTIAL

Article ID: AG-VO6-I10-03

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Introduction

Green leafy medicinal plants have been used in daily life in various ways since ancient times. They have traditionally served as basic remedies for several ailments and are also used as important ingredients in household cuisines. However, information on many of these leafy vegetables remains limited because their cultivation and use are often restricted to specific regions and localities. These vegetables possess high nutritional value and should be incorporated into the daily diet to improve health and nutritional security.

India is home to a large diversity of leafy vegetables with considerable nutritional potential. However, relatively little practical information is available on their production practices and quality characteristics. In recent years, some of these vegetables have attracted the attention of farmers and consumers, although their popularity is still largely region-specific. Greater emphasis needs to be placed on these crops to achieve nutritional and health security. Leafy vegetables are not only nutritious but also possess considerable medicinal and therapeutic value, and many of them have been traditionally used as remedies for various ailments since ancient times.

Among leafy vegetables, **amaranth** and **spinach (*Spinacia oleracea*)** are commercially cultivated on a large scale throughout the country. Some leafy vegetables, such as **bathua (*Chenopodium album*)**, **poi (*Basella alba/Basella rubra*)**, and **drumstick (*Moringa oleifera*)**, are predominantly region-specific crops. Because of their relatively high nutritional value and importance in food and nutritional security, these traditional leafy vegetables deserve greater attention and promotion. They also have considerable potential for income generation. Their

consumption adds diversity to the daily diet and enhances its flavour and taste. These vegetables are rich sources of vitamins, minerals, trace elements, dietary fibre and protein. Therefore, they are important from nutritional, ecological, agronomic and conservation perspectives.

1. Kalmi Saag (*Ipomoea aquatica*)

Common name: Water Spinach

Kalmi saag is a semi-aquatic and tropical plant cultivated for its tender shoots and leaves, which are used as a vegetable. Its leaves are good sources of minerals, vitamins, protein and dietary fibre. Being rich in iron, it may be beneficial as part of a diet for individuals suffering from iron deficiency. It is also considered a useful dietary vegetable for maintaining healthy body weight and supporting the management of cholesterol and triglyceride levels.

The plant is a creeping vine that grows in water or moist soil. Its stem is hollow and possesses distinct nodes from which roots develop, giving rise to new plants. Vegetative propagation can be easily carried out by planting stem cuttings in moist soil. The plant can also be propagated through seeds.

2. Sushni Saag/Choupatia (*Marsilea quadrifolia*)

Common names: European Water-clover, Water Shamrock

Sushni saag belongs to the family **Marsileaceae** and is distributed in parts of Europe and Asia. Traditionally, it has been used for various health-related purposes, including respiratory disorders, insomnia and hypertension. It is an aquatic to amphibious plant, with roots occurring in soil, mud or shallow ponds.

Vegetative propagation takes place through rhizomes, with branches arising near the base of the leaves. In submerged plants, the petioles are long, cylindrical and flexible. Each petiole bears four equal-sized leaflets at its tip. The leaves float on the surface of the water, giving the plant its characteristic four-leaf-clover appearance.

The plant can also reproduce through spores. It produces **sporocarps**, which require slight abrasion followed by immersion in water for germination. The sporocarps swell and rupture, releasing spores that germinate rapidly. The highly developed prothallus remains within the megaspore. The gametophytic generation is completed within approximately 24 hours, while the first roots and shoots appear within 2–3 days. Mature sporocarp-bearing plants can develop within about three months. Spore germination, gametophyte development and fertilization occur rapidly.



Brahmi



Helencha



Kulekhara



Asiatic Pennywort

Fig 1. Some Minor Leafy Medicinal Vegetables:

3. Helencha Saag (*Enhydra fluctuans*)

Common name: Buffalo Spinach

Enhydra fluctuans is an indigenous edible plant and is widely consumed in India. It belongs to the family **Asteraceae** and is highly valued for its traditional medicinal properties. It is distributed across many parts of India, particularly in the northeastern region. The plant commonly grows in marshy areas, near paddy fields and around ponds. It is consumed as a leafy vegetable in several parts of the country.

According to traditional Ayurvedic practices, the plant is considered to possess several medicinal properties and has been traditionally used for conditions associated with bile disorders, convulsions, epilepsy, gonorrhoea, hypertension, inflammation, liver disorders, nervous disorders, paralysis and skin diseases.

It is a floating or semi-aquatic plant with roots developing from the lower nodes. The stem is generally 30–60 cm long. The leaves are sessile, 2.5–7.5 cm long, linear to oblong, and either acute or obtuse. The stem is fleshy, hairy and branched. The fruits are achenes surrounded by hard receptacle scales.

4. Kulekhara (*Hygrophila auriculata*)

Common names: Swampweed, Marsh Barbel

Kulekhara is an important medicinal plant belonging to the family **Acanthaceae**. It is widely distributed in tropical and subtropical regions of India. Its medicinal properties have been recognized in traditional medical literature since ancient times.

The plant contains various bioactive compounds, including terpenoids, alkaloids and flavonoids. Traditionally, it has been recognized for its health-promoting properties and has been used as an aphrodisiac and for supporting kidney health.

Different parts of the plant, including the leaves, roots and seeds, have traditionally been used for various ailments such as inflammation, jaundice, hepatic disorders, urinary tract infections, oedema, arthritis, diabetes and bacterial infections. The roots and seeds have also traditionally been used as tonics for asthma and dysentery. In Ayurveda, the seeds and **panchanga**—the combined preparation of the root, flower, stem, fruit and leaves—are used medicinally.

The plant can be propagated through seeds as well as stem cuttings. Its stem is quadrangular, hairy and hard at the nodes and can grow up to about 60 cm in height. The flowers are purple in colour. The fruits are quadrangular to linear, smooth and approximately 1 cm long, containing hairy, brown seeds.

5. Brahmi (*Bacopa monnieri*)

Common name: Indian Pennywort

Brahmi is an important medicinal herb native to South and Southeast Asia and is traditionally known for its memory-enhancing properties. It belongs to the family **Plantaginaceae**.

According to traditional Ayurvedic medicine, the entire plant is used medicinally. It has been reported to possess several biological properties, including antitumour, antiviral and antigenotoxic activities. The leaves are succulent, oblong and approximately 4–6 mm thick. They are arranged oppositely along the stem.

Propagation is commonly carried out through stem cuttings. It is a creeping perennial herb with small oblong leaves and white flowers. The plant generally grows in warm and humid environments.

6. Gima Saag (*Glinus oppositifolius*)

Common name: Indian Chickweed

Glinus oppositifolius is a branched herb belonging to the family **Molluginaceae**. This leafy vegetable has a slightly bitter taste and is locally known as **Gima saag**. It commonly occurs as a weed in rice fields after harvesting.

Traditionally, the plant has been used for wound healing and for managing conditions such as diabetes, fever, inflammation, diarrhoea and intestinal and skin disorders. Its inclusion in a healthy diet may be beneficial, as it has been associated with positive effects on haemoglobin and serum ferritin levels.

The leaves contain various bioactive compounds, including triterpenoids, triterpenoid saponins and *Glinus oppositifolius*-derived compounds, some of which have demonstrated antifungal activity. The plant can be propagated by seeds as well as through stem cuttings.

7. Mandukaparni (*Centella asiatica*)

Common name: Asiatic Pennywort

Centella asiatica is an important tropical medicinal plant possessing medicinal, nutritional and cosmetic properties. It belongs to the family **Apiaceae** and is native to tropical regions of Africa, Asia, Australia and the islands of the western Pacific. It is consumed both as a cooked vegetable and as a medicinal plant.

The plant has been traditionally used in Chinese medicine and Ayurvedic medicine in India for wound healing, mental disorders and circulatory disorders. According to the *Charaka Samhita*, it is considered a useful medicinal plant for promoting longevity and delaying the effects of ageing.

It is a rhizomatous perennial herb that grows close to the ground and rapidly spreads to form a dense ground cover. The stems are thin, creeping stolons, ranging from green to reddish-green, which connect individual plants. The leaves have long petioles and rounded, smooth green blades. The flowers are white to reddish and occur in small, rounded clusters close to the soil surface.

Conclusion

Many green leafy plants have been used in traditional medicine for centuries. These leafy medicinal vegetables have diverse applications in promoting human health and well-being and can play an important role in daily diets. Over the past few decades, many traditionally cultivated

and consumed crops have gradually been replaced by a limited number of mainstream vegetables.

There is a need to conserve, promote and popularize these traditional leafy vegetables because of their nutritional, medicinal and economic importance. Their inclusion in regular diets can improve dietary diversity and contribute to nutritional security. In addition to providing essential minerals, vitamins, dietary fibre and other nutrients, several of these vegetables possess valuable bioactive compounds and traditional medicinal significance. Therefore, greater attention should be given to their scientific evaluation, cultivation, conservation and utilization as part of **smart, sustainable and nutrition-sensitive farming systems**.

Volume: 06 Issue No: 10

HEAT STRESS TOLERANCE IN VEGETABLE CROPS: CHALLENGES AND BREEDING APPROACHES

Article ID: AG-VO6-I10-04

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Abstract

Heat stress is becoming an increasingly important constraint to vegetable production due to rising global temperatures, frequent heat waves and unpredictable weather patterns. Vegetable crops are particularly sensitive to high temperature because many economically important species, including tomato, chilli, capsicum, brinjal, cucumber, beans, pea and lettuce, have relatively narrow optimum temperature ranges for growth, flowering, pollination and fruit development. Exposure to temperatures above the crop-specific optimum can adversely affect germination, seedling growth, photosynthesis, reproductive development, pollen viability, fruit set, yield and quality. Heat stress also induces oxidative damage, membrane instability, disruption of cellular metabolism and alterations in hormonal balance. Developing heat-tolerant cultivars is therefore an important component of climate-resilient vegetable production. Conventional breeding, exploitation of genetic variability, selection for physiological and morphological traits, hybridization, mutation breeding, marker-assisted selection, genomic selection, transcriptomics and genome-editing technologies offer opportunities for improving heat tolerance. Important traits such as pollen viability, fruit set under high temperature, canopy temperature, membrane stability, antioxidant activity, photosynthetic efficiency and heat-shock protein expression can facilitate selection. Combining conventional breeding with modern genomic and biotechnological approaches can accelerate the development of heat-tolerant vegetable cultivars. This article discusses the effects of heat stress on vegetable crops, mechanisms of tolerance, challenges in breeding and recent approaches for developing heat-resilient vegetable varieties.

Keywords: Heat stress, vegetable crops, abiotic stress, heat tolerance, climate resilience

Introduction

Vegetable crops constitute an important component of human diets because they provide vitamins, minerals, dietary fibre, antioxidants and a wide range of bioactive compounds. They also contribute substantially to farm income and employment. However, vegetable production is highly sensitive to environmental fluctuations. Among different abiotic stresses, high temperature or heat stress is emerging as one of the major threats to sustainable vegetable production.

Heat stress may be defined as a rise in temperature beyond the optimum range required for normal growth and development of a crop for a sufficient duration to cause irreversible physiological, biochemical and reproductive damage. The intensity of damage depends on the magnitude and duration of temperature elevation, crop species, genotype, developmental stage, humidity, water availability and interaction with other stresses.The effects of increasing temperature are particularly important in vegetables because many vegetable crops are grown for their tender leaves, immature fruits, mature fruits, roots, bulbs or reproductive structures. Consequently, even moderate disturbances in vegetative growth, flowering, pollination or fruit development can result in considerable economic losses.

High temperature can affect vegetable crops throughout the crop cycle. Germination may be reduced, seedlings may become weak, vegetative growth may be restricted, flowering may be abnormal, pollen viability may decline and fruit set may be drastically reduced. In crops, such as tomato and pepper, high temperature during flowering is particularly damaging because reproductive processes are generally more sensitive to heat than vegetative growth. Development of heat-tolerant vegetable cultivars is therefore an important long-term strategy for maintaining vegetable productivity under changing climatic conditions.

Causes and Nature of Heat Stress

Heat stress occurs when plants are exposed to temperatures above their optimum physiological range. The critical temperature varies considerably among vegetable species and even among cultivars of the same species.

Heat stress can occur as short-duration heat waves, prolonged periods of high temperature, high night-time temperature, high temperature combined with drought, high temperature accompanied by high humidity or sudden temperature fluctuations.

The combination of high temperature and water deficit is particularly damaging. Under field conditions, heat stress rarely occurs independently. Plants frequently experience simultaneous heat, drought, salinity and nutrient stresses. This makes the development of broadly adapted cultivars more challenging.

Effects of Heat Stress on Vegetable Crops

1. **Effects on Seed Germination**

Temperature influences seed germination, enzyme activity and early seedling establishment. Exposure to temperatures above the optimum can reduce germination percentage and germination rate. High temperature may disturb water uptake, membrane integrity and enzymatic processes involved in seed germination. Heat-sensitive crops may show delayed or uneven emergence under high-temperature conditions. Poor seedling establishment ultimately results in reduced plant population and yield.

2. **Effects on Vegetative Growth**

Heat stress affects several aspects of vegetative growth including leaf expansion, shoot growth, root development, biomass accumulation, stomatal regulation, photosynthesis, respiration and water relations. High temperature can increase transpiration and respiration while reducing photosynthetic efficiency. Prolonged heat exposure may cause leaf scorching, premature senescence and reduction in total biomass. Root growth may also be altered, affecting water and nutrient uptake. Under combined heat and drought stress, these effects become more pronounced.

3. **Effects on Photosynthesis**

Photosynthesis is one of the major physiological processes affected by heat stress. High temperature can damage the photosynthetic apparatus, alter chloroplast structure and reduce the efficiency of photosystem II. Heat stress may cause reduction in chlorophyll content, decline in stomatal conductance, reduced carbon assimilation, increased photorespiration, damage to photosynthetic proteins and increased production of reactive oxygen species. Genotypes capable of maintaining higher photosynthetic activity under heat stress may have greater potential for heat tolerance.

Effect of Heat Stress on Flowering and Reproductive Development

The reproductive stage is often the most heat-sensitive stage in many vegetable crops. High temperature can influence flower initiation, flower development, anther development,

pollen formation, pollen viability, pollen germination, pollen tube growth, ovule development, fertilization and fruit set. In tomato, for example, excessive temperature during flowering can reduce pollen viability and pollen release, resulting in poor fruit set. Similar reproductive effects have been observed in pepper and other fruit-bearing vegetables.

Pollen viability as a selection criterion

Pollen viability is considered an important indicator of heat tolerance because pollen development is highly sensitive to temperature. Heat-tolerant genotypes generally maintain greater pollen viability and pollen germination under high-temperature conditions. Therefore, screening genotypes during the flowering stage can be particularly useful for breeding programmes.

Effect on Yield and Fruit Quality

Heat stress can cause substantial reductions in vegetable yield through poor flowering, reduced fruit set, flower abortion and impaired fruit development. In addition to yield reduction, heat stress can influence quality attributes such as fruit size, shape, colour, firmness, soluble solids, acidity, vitamin content, antioxidant compounds and nutritional quality. Thus, heat tolerance breeding should focus not only on maintaining yield but also on preserving desirable quality characteristics.

Physiological and Biochemical Mechanisms of Heat Tolerance

Heat tolerance is a complex trait controlled by multiple physiological, biochemical and genetic mechanisms.

1. **Maintenance of Cell Membrane Stability**

High temperature can increase membrane fluidity and cause leakage of cellular electrolytes. Heat-tolerant genotypes generally maintain greater membrane stability. Electrolyte leakage and relative water content are therefore commonly used as physiological indicators during heat tolerance screening.

2. **Antioxidant Defence**

Heat stress increases the production of reactive oxygen species (ROS), including Superoxide radicals, Hydrogen peroxide and Hydroxyl radicals. Excessive ROS can damage proteins, lipids, membranes and nucleic acids. Plants possess antioxidant defence systems involving enzymes such as Superoxide dismutase (SOD), Catalase (CAT), Ascorbate peroxidase (APX), Glutathione

reductase (GR), Peroxidase (POD). Heat-tolerant genotypes may possess stronger antioxidant defence systems that help minimize oxidative damage.

3. **Heat-Shock Proteins**

Heat-shock proteins (HSPs) are among the most important molecular components of plant heat-stress responses. They function primarily as molecular chaperones and help stabilize proteins, prevent protein aggregation, assist protein refolding, protect cellular structures and maintain protein homeostasis. Enhanced expression of heat-shock proteins can contribute to improved cellular protection under high-temperature conditions.

4. **Osmotic Adjustment**

Heat stress can disturb cellular water balance. Plants respond through accumulation of osmo-protective compounds such as proline, soluble sugars, glycine betaine and polyols. These compounds help maintain cellular water status and protect proteins and membranes.

Genetic Basis of Heat Tolerance

Heat tolerance is generally a complex quantitative trait influenced by multiple genes and their interaction with the environment. The expression of heat tolerance may vary with developmental stage, temperature intensity, duration of stress, genetic background, soil moisture, relative humidity and photoperiod. Because of this complexity, selection based on a single trait is usually insufficient. A combination of morphological, physiological, biochemical and molecular traits provides a more reliable basis for identifying tolerant genotypes.

Conventional Breeding Approaches

1. **Exploration of Genetic Variability**

The first step in heat tolerance breeding is identification of genetic variability. Breeding programmes can utilize Landraces, Traditional cultivars, Germplasm collections, Wild relatives, Exotic introductions, Advanced breeding lines, Existing heat-tolerant cultivars, etc. Screening diverse germplasm under controlled and field heat-stress conditions can help identify promising donor parents.

2. **Selection**

Selection can be performed based on traits associated with heat tolerance. Important selection criteria include high fruit set under heat, pollen viability, pollen germination, canopy temperature, membrane stability, relative water content, chlorophyll retention, photosynthetic efficiency, antioxidant activity, reduced flower abortion and stable yield. Indirect selection using

physiological traits may improve breeding efficiency when direct yield evaluation under heat stress is difficult.

3. Hybridization

Hybridization is one of the most important conventional approaches. A heat-tolerant genotype can be crossed with an agronomically superior but heat-sensitive genotype to combine:

Heat tolerance + high yield + desirable quality + disease resistance

The segregating generations can subsequently be evaluated under heat-stress conditions.

4. Backcross Breeding

When a heat-tolerant donor has undesirable horticultural characteristics, backcross breeding can be used to transfer heat tolerance into an elite cultivar.

The general procedure is:

Heat-tolerant donor × elite susceptible parent → F_1 → backcrossing → selection for heat tolerance → repeated backcrossing → selection → advanced line

This approach is particularly useful when the tolerant trait has a manageable genetic basis or when reliable molecular markers are available.

Heterosis Breeding

Hybrid breeding offers considerable opportunities for developing heat-resilient vegetable cultivars. Hybrids may exhibit superior performance through heterosis for yield, early growth, root development, stress tolerance, fruit set and physiological efficiency. Heat tolerance can therefore be incorporated into parental lines followed by hybrid development and evaluation under high-temperature conditions. However, heat tolerance should be evaluated directly in hybrid combinations because parental performance does not always predict hybrid performance under stress.

Mutation Breeding

Mutation breeding can generate novel genetic variability for heat tolerance. Physical mutagens such as Gamma radiation, X-rays and chemical mutagens such as EMS, Sodium azide can be used to create genetic variation. Mutant populations can subsequently be screened for improved performance under high temperature. Mutation breeding may be particularly useful where naturally occurring heat-tolerant variability is limited.

Marker-Assisted Selection

Molecular markers provide an opportunity to improve the efficiency of conventional breeding. Quantitative trait loci (QTLs) associated with traits such as heat tolerance, pollen viability, fruit set, canopy temperature, membrane stability, yield under heat stress, etc. can potentially be identified and utilized in marker-assisted selection. Marker-assisted breeding can reduce the dependence on phenotypic screening, particularly for traits that are difficult, expensive or environmentally variable to measure.

Genomic Selection

Genomic selection represents a further advancement in breeding for complex traits. Instead of identifying a small number of markers associated with a trait, genomic selection uses genome-wide marker information to predict the breeding value of individuals. This approach has particular potential for heat tolerance because the trait is generally controlled by many genes with small effects.

The general strategy involves:

Training population → phenotyping under heat stress → genome-wide genotyping → genomic prediction model → selection of superior individuals → field validation

Transcriptomics and Functional Genomics

Transcriptomic studies can identify genes that are differentially expressed under heat stress. Genes involved in heat-shock response, antioxidant defence, hormonal signalling, osmotic adjustment, photosynthesis, protein folding and membrane protection can be investigated. RNA sequencing and related approaches can help identify candidate genes and regulatory networks involved in heat tolerance. Such information can subsequently support marker development and targeted breeding.

Genome Editing

Genome-editing technologies, particularly CRISPR-based approaches, have opened new possibilities for crop improvement. Potential targets include genes involved in heat sensing, stress signalling, hormonal regulation, antioxidant defence, transcriptional regulation and heat-shock protein pathways. Genome editing could allow precise modification of genes associated with stress responses. However, extensive validation is necessary to determine whether the resulting plants show stable heat tolerance without undesirable effects on yield, quality or other agronomic traits.

Important Vegetable Crops for Heat-Tolerance Breeding

Tomato

Tomato is highly sensitive to high temperature during flowering. Heat stress can reduce pollen viability, pollen germination and fruit set. Breeding efforts should emphasize heat-tolerant lines that maintain reproductive performance under high-temperature conditions.

Chilli and Capsicum

High temperature can influence flowering, pollen viability, fruit set and fruit development. Heat-tolerant parental lines can be used in hybrid breeding programmes.

Brinjal

Brinjal generally possesses considerable adaptability to warm conditions, but extreme temperature can affect flowering and fruit development. Genetic variability within germplasm can be exploited for developing better-adapted cultivars.

Cucumber

High temperature can influence vegetative growth, sex expression, flowering and fruit quality. Heat-tolerant genotypes with stable fruit production under elevated temperatures are valuable for future breeding programmes.

Beans

High temperature can reduce flowering, pollen viability and pod setting. Heat tolerance is therefore important for maintaining bean productivity in warmer environments.

Lettuce and Other Cool-Season Vegetables

Lettuce, spinach, pea, broccoli and several other cool-season crops are particularly vulnerable to high temperature. Heat can accelerate bolting, reduce head quality and alter nutritional characteristics.

Screening Methods for Heat Tolerance

Efficient screening is essential for breeding programmes.

1. **Field Screening**

Genotypes are grown during naturally occurring high-temperature periods and evaluated for survival, growth, flowering, fruit set, yield and quality.

Field screening is highly relevant because it exposes plants to realistic environmental conditions.

2. **Controlled Environment Screening**

Growth chambers, glasshouses and polyhouses can be used to impose controlled heat stress.

Advantages include uniform stress, precise temperature control, reproducibility, screening at specific developmental stages. However, controlled environments may not fully represent field conditions.

Challenges in Breeding for Heat Tolerance

Despite advances in breeding and biotechnology, several challenges remain.

1. **Complex inheritance**

Heat tolerance is generally controlled by multiple genes, making simple selection difficult.

2. **Genotype × environment interaction**

A genotype performing well in one environment may not necessarily perform similarly under another temperature regime.

3. **Multiple stress interactions**

Heat stress frequently occurs together with drought, salinity or nutrient stress.

4. **Reproductive-stage sensitivity**

Tolerance during vegetative growth does not necessarily guarantee tolerance during flowering and fruit setting.

5. **Limited reliable screening protocols**

Standardized and reproducible screening methods are still needed for several vegetable crops.

6. **Yield–stress tolerance trade-offs**

Some stress-tolerant genotypes may not possess desirable yield, quality or market traits.

7. **Limited genetic resources**

For some vegetables, sufficient information about sources of heat tolerance and their underlying genes is still unavailable.

8. **Integrated Breeding Strategy for Heat-Tolerant Vegetables**

A successful breeding programme should integrate multiple approaches.

Germplasm collection

↓

Characterization and evaluation

↓

Heat-stress screening

↓

Identification of tolerant donors

↓

Physiological and biochemical characterization

↓

Hybridization with elite cultivars

↓

Selection under heat stress

↓

Marker/QTL identification

↓

Marker-assisted or genomic selection

↓

Multi-location evaluation

↓

Quality and yield assessment

↓

Release of heat-tolerant cultivar

This integrated strategy can shorten the breeding cycle and increase the probability of developing cultivars with stable performance.

Future Prospects

The future of heat-tolerance breeding will increasingly depend on integration of conventional breeding, high-throughput phenotyping, genomics, molecular breeding and precision biotechnology. High-throughput phenotyping platforms can measure canopy temperature, vegetation indices, chlorophyll fluorescence and growth characteristics rapidly across large populations. Artificial intelligence and machine learning can assist in analysing complex phenotypic datasets and identifying relationships between traits and stress tolerance. Genomic selection can accelerate improvement of polygenic traits, while genome editing may enable targeted modification of genes involved in heat-stress responses. Another important area is speed breeding, which can shorten generation intervals and increase the number of breeding cycles possible within a given period.

Future breeding programmes should also focus on combined stress tolerance, because farmers generally experience heat stress together with drought and other environmental constraints rather than as isolated stresses.

Conclusion

Heat stress represents a major challenge to sustainable vegetable production, particularly in regions experiencing increasing temperatures and more frequent heat waves. Its effects extend from seed germination and vegetative growth to flowering, pollen viability, fruit setting, yield and quality. Reproductive development is especially vulnerable in many vegetable crops.

Developing heat-tolerant cultivars is therefore an essential component of climate-resilient horticulture. Genetic variability available in germplasm, landraces, traditional cultivars and wild relatives provides the foundation for breeding. Conventional approaches such as selection, hybridization, backcrossing and heterosis breeding can be strengthened through physiological and biochemical screening. Modern approaches including molecular markers, QTL mapping, genomic selection, transcriptomics, high-throughput phenotyping and genome editing offer new opportunities to accelerate the development of heat-tolerant cultivars. The integration of these technologies with conventional breeding will be particularly important for complex traits such as heat tolerance.

Ultimately, breeding vegetables that can maintain flowering, pollen viability, fruit set, yield and quality under elevated temperatures will contribute significantly to food and nutritional security and to the resilience of vegetable-based farming systems under a changing climate.

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Volume: 06 Issue No: 10

AGRICULTURE, MAJOR CROPS, VEGETABLE PRODUCTION, AND THE PROSPECTS OF AI TECHNOLOGY FOR MARGINAL FARMERS IN UTTAR PRADESH

Article ID: AG-VO6-I10-05

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Abstract

Uttar Pradesh forms the backbone of India's agrarian economy, characterized by an overwhelming majority of small and marginal farmers who cultivate land parcels typically less than one hectare. While these farmers display remarkable resilience, they face mounting challenges, including fragmented landholdings, unpredictable climatic variations, soaring input costs, and limited access to modern market intelligence. This article explores the holistic agricultural ecosystem of Uttar Pradesh, analyzing traditional major crops, the expanding economic potential of horticulture and vegetable production, and the revolutionary role that Artificial Intelligence (AI) can play in transforming marginal farming into a profitable, sustainable enterprise.

1. Introduction: The Socio-Economic Realities of Marginal Farmers in Uttar Pradesh

Uttar Pradesh is India's most populous state, with over 70% of its population directly or indirectly dependent on agriculture. According to agricultural census data, marginal farmers (owning less than 1 hectare of land) constitute nearly 80% of the total landholdings in the state.

For these farmers, agriculture is not merely a commercial venture; it is a vital means of livelihood and food security. However, marginal farming in the Indo-Gangetic plains faces structural bottlenecks:

- **Extreme Land Fragmentation:** Holdings are often split into non-contiguous plots, complicating mechanization and irrigation management.
- **Resource Constraints:** Limited capital access restricts the timely procurement of quality seeds, fertilizers, and advanced farm implements.

- **Climate Vulnerability:** Heavy reliance on erratic monsoons exposes marginal cultivators to severe crop losses due to droughts or unseasonal floods.

Addressing these vulnerabilities requires a paradigm shift that integrates traditional agronomic wisdom with modern engineering and digital innovations, particularly Artificial Intelligence (AI).

2. Major Agricultural Crops in Uttar Pradesh and Marginal Landholding Dynamics

The diverse agro-climatic zones of Uttar Pradesh—ranging from the fertile alluvial plains of the central region to the semi-arid tracts of the southwest (including Etawah)—support a diverse cropping pattern.

Primary Staple Crops

- **Wheat (Rabi):** Cultivated extensively across the state, wheat is the primary winter staple. Marginal farmers utilize high-yielding dwarf varieties, though timely irrigation remains a challenge due to high energy and equipment costs.
- **Paddy / Rice (Kharif):** A dominant monsoon crop requiring substantial water inputs. For marginal farmers, optimizing water use efficiency through micro-irrigation is critical.
- **Sugarcane (Cash Crop):** Prominent in western and parts of central UP, sugarcane yields high returns, but delayed payment cycles from sugar mills often create cash flow crises for smaller growers.
- **Millets and Pulses (Nutri-Cereals):** Crops like bajra, jowar, arhar, and gram thrive well in drier zones (like the Yamuna ravines around Etawah) and are resilient choices for marginal landholdings with low irrigation access.

3. Vegetable Production: A Viable Economic Lifeline for Small and Marginal Farmers

Given the constraints of limited land acreage, traditional cereal cultivation alone often fails to generate adequate income for marginal households. Horticultural diversification, particularly vegetable production, offers a lucrative alternative.

- **Higher Economic Returns per Unit Area:** Vegetables such as potatoes, tomatoes, onions, cauliflowers, and cucurbits have shorter crop cycles and yield significantly higher financial returns per hectare compared to cereals.
- **Nutritional Security:** Local vegetable cultivation ensures a balanced diet and surplus marketable produce for rural households.

- **Protected Cultivation & Nursery Raising:** Low-cost polyhouses and shade-net structures, promoted through state and central horticultural missions, allow marginal farmers to produce off-season high-value vegetables, fetching premium market prices.

4. The Role of Modern Engineering and Smart Technologies in Marginal Farming

As a faculty member in agricultural technology, I observe that mechanization has traditionally favored large-scale farmers. However, modern agricultural engineering is pivoting toward scale-neutral technologies:

- **Mini-Tractors and Power Tillers:** Compact machinery designed specifically for small, fragmented plots.
- **Precision Irrigation Systems:** Solar-powered micro-sprinklers and drip irrigation kits that drastically reduce water and labor overheads.
- **Post-Harvest Management:** Low-cost on-farm storage solutions and primary processing units to minimize post-harvest losses and enhance bargaining power.

5. Artificial Intelligence (AI) in Agriculture: Transforming Traditional Practices

Artificial Intelligence is no longer confined to futuristic laboratories; it is rapidly redefining grassroots agriculture. AI bridges the gap between complex scientific data and grassroots farm execution by processing massive data sets (weather telemetry, soil composition, satellite imagery) into simple, actionable insights.

For marginal farmers in Uttar Pradesh, AI-driven tools can democratize access to expert agronomic advice, leveling the playing field against large commercial agri-enterprises.

6. AI-Driven Solutions for Marginal Farmers: Practical Applications

1. Smart Crop and Soil Health Management

AI-powered applications integrated with IoT soil sensors or image recognition can analyze soil nutrient deficiencies rapidly. Instead of blanket fertilizer application, marginal farmers receive precise, plot-specific recommendations for nitrogen, phosphorus, and potassium (NPK), cutting input costs significantly.

2. Early Pest and Disease Detection Using Smartphone Vision

Crop pests like the Fall Armyworm or diseases like wheat yellow rust can devastate a marginal farmer's entire harvest. Using vernacular AI mobile applications, a farmer can simply snap a photo of an affected leaf. The AI model instantaneously diagnoses the pathology and recommends organic or chemical control measures.

3. Hyper-Local Weather Forecasting and Irrigation Advisory

Unseasonal rain and frost cause heavy losses in Uttar Pradesh. AI algorithms combine meteorological satellite data with local topographical models to deliver hyper-local weather alerts via SMS or voice bots, enabling farmers to schedule harvesting, sowing, or irrigation optimally.

4. Market Intelligence and Dynamic Pricing

Marginal farmers often fall victim to distress selling due to a lack of market information. AI-driven platforms predict demand-supply fluctuations and advise farmers on optimal harvesting windows and the most profitable local mandis (markets) or direct-to-consumer digital supply chains.

7. Policy Frameworks, Institutional Support, and Extension Services

Technology adoption cannot succeed in a vacuum. Successful transformation requires coordinated institutional backing:

- **Krishi Vigyan Kendras (KVKs):** Serving as grassroots catalysts, KVKs (such as those associated with CSAUA&T across various districts including Etawah) must act as demonstration hubs for AI tools and smart farming kits.
- **Digital Public Infrastructure:** Expansion of initiatives like Krishi-Decision Support Systems and digital soil health cards integrated with mobile platforms.
- **Credit and Financial Inclusion:** Streamlining Kisan Credit Cards (KCC) and institutional micro-loans to help marginal farmers invest in micro-irrigation and digital tools.

8. Conclusion and Future Roadmap

The marginal farmers of Uttar Pradesh possess immense grit and form the bedrock of regional food security. While their small land sizes pose structural hurdles, the integration of high-value horticulture with cutting-edge AI technologies offers a transformative pathway out of agrarian distress. By shifting toward data-driven, precision agriculture, Uttar Pradesh can pioneer a new era of inclusive rural prosperity—ensuring that even the smallest landholder reaps the maximum benefit of scientific advancement.

Volume: 06 Issue No: 10

ANTIBACTERIAL ACTIVITY OF SEAWEED EXTRACTS AGAINST FISH PATHOGENS

Article ID: AG-VO6-I10-06

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Abstract

Seaweeds are important marine resources containing a wide variety of biologically active compounds with nutritional, pharmaceutical and industrial applications. They are broadly classified into green, brown and red seaweeds. In recent years, seaweeds have attracted considerable attention as natural sources of compounds because they contain phenolics, phlorotannins, flavonoids, terpenoids, fatty acids, pigments and sulphated polysaccharides. Bacterial diseases are among the major constraints affecting intensive aquaculture. Pathogens belonging to the genera Aeromonas, Vibrio, Pseudomonas and Edwardsiella can cause serious infections, mortality and economic losses in cultured fish and other aquatic animals. The increasing problem of antimicrobial resistance has created a need for alternative and sustainable disease-management approaches. Several studies have reported that extracts obtained from marine macroalgae can inhibit the growth of important bacterial pathogens. The antibacterial activity of seaweed extracts is influenced by seaweed species, geographical origin, season, extraction solvent, concentration and target bacterial species. Brown seaweeds are particularly rich in phlorotannins and fucoidan, while red and green seaweeds contain bioactive polysaccharides and other compounds that may contribute to antimicrobial activity. Seaweed-derived compounds therefore have potential for application in sustainable aquaculture. However, further research is necessary to establish their safety, effective dosage, mechanisms of action and practical efficacy under aquaculture conditions.

Keywords: Seaweed, macroalgae, antibacterial activity, fish pathogens, aquaculture, bioactive compounds, phlorotannins, antimicrobial resistance.

1. Introduction

Aquaculture has become an important source of food, employment and income throughout the world. The rapid expansion of fish and shellfish farming has increased production efficiency but has also created favourable conditions for the emergence and spread of infectious diseases. Bacterial diseases are among the most important health problems in aquaculture and can result in mortality, reduced growth, poor feed utilization and economic losses. Common bacterial pathogens affecting cultured aquatic animals include Aeromonas hydrophila, Aeromonas salmonicida, Vibrio anguillarum, Vibrio harveyi, Vibrio parahaemolyticus, Pseudomonas spp. and Edwardsiella spp. Disease outbreaks are often associated with environmental stress, poor water quality, high stocking density, nutritional deficiencies and inadequate biosecurity.Antibiotics have traditionally been used for the treatment of bacterial diseases.

However, inappropriate or excessive antimicrobial use can contribute to the development of antimicrobial-resistant microorganisms. Antimicrobial resistance is a major global health concern, and responsible antimicrobial use in food-producing animals, including aquaculture, is increasingly emphasized.Seaweeds provide a promising source of natural bioactive substances. They are exposed continuously to microorganisms in the marine environment and produce various chemical compounds that may contribute to their defence. Many of these compounds possess antibacterial, antioxidant, antiviral, antifungal and anti-inflammatory properties.Research on seaweed-derived antibacterial compounds is therefore important for the development of natural products that could complement existing disease-management strategies in aquaculture.

2.Classification and Bioactive Components of Seaweeds Seaweeds are commonly divided into three major groups: green, brown and red algae.

2.1 Green seaweeds

Green seaweeds belong mainly to Chlorophyta and include genera such as Ulva, Caulerpa and Codium. They contain chlorophylls, carotenoids, proteins, fatty acids, phenolic compounds and polysaccharides. Ulvan, a sulphated polysaccharide found mainly in Ulva species, has received attention for its biological activities. Green seaweed extracts have shown antimicrobial activity against several bacterial species. The

activity may be associated with phenolic compounds, fatty acids, polysaccharides and other secondary metabolites.

2.2 Brown seaweeds

Brown seaweeds include Sargassum, Fucus, Ecklonia, Laminaria, Padina and Undaria. They are rich in alginate, fucoidan, laminarin, carotenoids and phlorotannins. Phlorotannins are characteristic phenolic compounds of brown algae and are considered important contributors to their antimicrobial properties. Several phlorotannins have been shown to affect bacterial growth through interactions with cellular membranes and proteins.

2.3 Red seaweeds

Red seaweeds belong mainly to Rhodophyta and include Gracilaria, Kappaphycus, Gelidium and Porphyra. They are commercially important because they are sources of agar and carrageenan.Red seaweeds also contain phenolic compounds, pigments, fatty acids and other metabolites that may exhibit antimicrobial activity. Carrageenan and other sulphated polysaccharides have attracted attention because of their diverse biological properties.The chemical composition of seaweeds varies according to species, season, geographical location, environmental conditions and physiological stage. Therefore, antibacterial activity can differ considerably between seaweed species.



Green seaweed

Eg: Ulva



Brown seaweed

Eg: Sargassum



Red seaweed

Eg: Kappaphycus

3. Fish Pathogens and Aquaculture Diseases

3.1 Aeromonas species :

Aeromonas hydrophila is an important freshwater fish pathogen associated with motile aeromonad septicemia. Infected fish may show skin ulcers, haemorrhages, fin erosion and internal organ damage. The bacterium is particularly problematic when fish experience

environmental or physiological stress. Aeromonas salmonicida is another important fish pathogen associated with furunculosis and other infections. These bacteria are frequently used in laboratory studies evaluating natural antibacterial compounds.

3.2 Vibrio species :

Vibrio species are important pathogens in marine and brackish-water aquaculture. Vibrio anguillarum, Vibrio harveyi, Vibrio alginolyticus and Vibrio parahaemolyticus have been associated with disease outbreaks in fish and shellfish.

Vibrio infections may become severe under stressful environmental conditions. Therefore, natural products with activity against these bacteria are of particular interest to marine aquaculture.

3.3 Pseudomonas species :

Pseudomonas species can act as opportunistic pathogens in cultured fish. Infections may produce skin lesions, fin damage and systemic disease, especially when fish are stressed or environmental conditions are poor.

3.4 Edwardsiella species :

Edwardsiella species are associated with systemic infections in several fish species. Their importance as fish pathogens has encouraged research into alternative methods for controlling bacterial diseases.

4. Antibacterial Activity of Seaweed Extracts:

The antibacterial properties of seaweeds have been investigated using extracts prepared with different solvents. Bansemir et al. (2006) screened cultivated seaweeds for antibacterial activity against several fish pathogenic bacteria, including Aeromonas salmonicida, Aeromonas hydrophila, Pseudomonas anguilliseptica, Vibrio anguillarum and Yersinia ruckeri. Their findings demonstrated that seaweeds can contain compounds with activity against bacteria important to aquaculture.

Genovese et al. (2017) also evaluated marine macroalgae against bacterial pathogens relevant to aquaculture and human health. Their findings indicated that macroalgal extracts and polysaccharide fractions can show antibacterial activity, although the degree of inhibition varied among species and bacterial strains.

Cox et al. (2010) investigated the antioxidant and antimicrobial properties of six edible

Irish seaweeds. Their study demonstrated variation in antimicrobial activity between seaweed species and extracts, emphasizing the influence of chemical composition and extraction method.

These studies indicate that seaweeds are promising sources of antibacterial substances. However, laboratory inhibition does not automatically indicate that an extract will be effective in a live fish or aquaculture system.

5. Important Antibacterial Compounds in Seaweeds

5.1 Phenolic compounds :

Phenolic compounds are important secondary metabolites found in many seaweeds. They can interact with bacterial proteins and membranes and may interfere with microbial metabolism.

5.2 Phlorotannins :

Phlorotannins are characteristic phenolic compounds of brown algae. They are formed from phloroglucinol units and include several structurally diverse compounds. Research has demonstrated antibacterial activity for several phlorotannins. Their proposed mechanisms include alteration of bacterial membrane permeability, interaction with proteins and inhibition of cellular processes.

5.3 Sulphated polysaccharides :

Seaweeds contain several important polysaccharides. Brown algae contain fucoidan and laminarin, green algae contain ulvan and red algae contain carrageenan and other galactans.

These compounds may interact with microbial surfaces and influence bacterial growth. Their biological activity depends on molecular weight, degree of sulphation, chemical structure and extraction conditions.

5.4 Fatty acids :

Seaweed lipids include saturated and unsaturated fatty acids. Some fatty acids can interfere with bacterial membranes and may contribute to the antimicrobial properties of seaweed extracts.

5.5 Terpenoids, pigments and other compounds :

Terpenoids, carotenoids, lectins, alkaloids and other secondary metabolites have also been investigated for antimicrobial activity. The antibacterial effect of a crude seaweed extract is therefore likely to result from the combined action of several compounds.

6. Mechanisms of Antibacterial Action :

Seaweed compounds can inhibit bacteria through several possible mechanisms.

Membrane disruption Some bioactive compounds interact with bacterial cell membranes and increase membrane permeability. This can result in leakage of intracellular substances and loss of cellular integrity.

Protein interaction Phenolic compounds may interact with bacterial proteins and enzymes, altering their structure and function. Enzyme inhibition can interfere with essential metabolic pathways.

Metabolic interference Certain seaweed-derived compounds may interfere with bacterial energy production and other metabolic processes required for growth.

Biofilm inhibition Biofilms provide bacteria with protection against environmental stress and antimicrobial agents. Some marine natural products have been investigated for their ability to interfere with bacterial attachment and biofilm formation.
The presence of multiple bioactive compounds may allow a seaweed extract to act on several bacterial targets simultaneously.

7. Methods for Evaluating Antibacterial Activity

7.1 Preparation of seaweed extract :

Seaweed material is generally washed to remove epiphytes, sand and other contaminants. It is then dried under suitable conditions and powdered. The powder is extracted using a selected solvent.Water, ethanol and methanol are commonly used in laboratory investigations. The solvent determines the type and quantity of compounds extracted.

7.2 Agar diffusion method :

The agar diffusion method is widely used for preliminary antibacterial screening. The test bacterium is inoculated onto a suitable agar medium and the seaweed extract is applied to wells or discs. Following incubation, the diameter of the inhibition zone is measured in millimetres. A larger inhibition zone indicates stronger growth inhibition under the particular experimental conditions.

7.3 Minimum inhibitory concentration :

The minimum inhibitory concentration (MIC) is the lowest concentration of an extract that prevents visible bacterial growth. MIC determination provides quantitative information and is useful for comparing antibacterial potency.

7.4 Importance of controls :

Proper positive and negative controls are essential. The extraction solvent should be

tested separately to determine whether it has antibacterial activity. A suitable reference antibacterial agent can be used as a positive control.

8. Factors Influencing Antibacterial Activity :

Several factors influence the antibacterial activity of seaweed extracts. Seaweed species: Different species contain different concentrations and types of bioactive compounds.Extraction solvent: Polar and non-polar solvents extract different chemical constituents. Extract concentration: Antibacterial activity may increase with increasing concentration, although the response varies between extracts. Season: Environmental changes can influence the concentration of secondary metabolites.Geographical location: Seaweeds collected from different habitats may show different chemical profiles.Bacterial species: Bacteria vary in their susceptibility to natural antibacterial compounds.Storage conditions: Light, temperature, oxygen and storage duration can affect the stability of bioactive compounds. These factors must therefore be carefully controlled when comparing antibacterial activity between seaweed samples.

9. Potential Applications in Aquaculture :

Seaweed-derived antibacterial compounds have several possible applications in aquaculture. Feed supplements Seaweed and seaweed-derived products may be incorporated into aquaculture feeds. In addition to potential antibacterial activity, seaweed ingredients can provide nutrients and bioactive compounds that may support fish health.Natural disease-management products Purified seaweed compounds may be developed into natural antimicrobial products. Such products could potentially form part of integrated disease-management programmes. Preventive health strategies Disease prevention should involve good water quality, appropriate stocking density, balanced nutrition, biosecurity and other management practices. Seaweed-based products could potentially complement these measures. Sustainable aquaculture The development of marine-derived natural products could contribute to reducing unnecessary dependence on conventional antimicrobials. However, their safety and effectiveness must be demonstrated before commercial application.

10. Seaweed and Antimicrobial Resistance :

Antimicrobial resistance is an increasing concern in aquaculture and other food-production systems. Repeated or inappropriate use of antibiotics can select for resistant bacteria.

The use of natural products is being explored as one component of a broader approach to responsible disease management. Seaweed-derived compounds may provide new chemical structures for antimicrobial research and could potentially help reduce unnecessary antimicrobial use. However, natural products are not automatically safe or resistance-free. Bacteria may also develop reduced susceptibility to natural antimicrobial compounds. Therefore, responsible use, scientific evaluation and monitoring remain essential. The most appropriate approach is an integrated strategy combining disease prevention, good husbandry, biosecurity, vaccination where applicable, pathogen diagnosis and responsible use of approved veterinary medicines.

11. Advantages and Limitations

Advantages:

- Seaweeds are renewable marine resources.
- They contain diverse bioactive compounds.
- Different species provide different chemical profiles.
- They may possess antibacterial and other beneficial biological activities.
- Seaweed cultivation can be integrated into sustainable marine production systems.
- Seaweed biomass has potential for multiple-value applications.

Limitations

Despite their potential, several challenges remain. The chemical composition of seaweeds varies with environmental conditions, making standardization difficult. Crude extracts may contain many compounds, and identifying the actual antibacterial molecule can be challenging. Many studies have been conducted under laboratory conditions. More in vivo studies are required to determine whether the observed antibacterial activity can be reproduced safely in cultured fish. Toxicity, dosage, stability, cost of extraction and effects on beneficial microorganisms also require careful investigation.

12.Future Perspectives :

Future research should focus on identifying the specific compounds responsible for antibacterial activity using chromatographic and spectroscopic techniques. Standardized extraction protocols should also be developed to allow meaningful comparison between studies. The determination of MIC and MBC values should be combined with inhibition-zone assays. Researchers should also investigate the effects of seaweed compounds on bacterial biofilms and virulence factors.

More in vivo research is required to determine appropriate doses, safety and effectiveness in cultured fish. Studies should evaluate not only the pathogen but also the host animal, beneficial microbiota and surrounding environment.

The development of seaweed-based products should follow a systematic process: selection of promising seaweed species, extraction, screening, identification of active compounds, toxicity evaluation, formulation and controlled animal trials.

Such research could contribute to the development of environmentally responsible approaches to aquaculture health management.

Conclusion

Seaweeds are valuable marine resources containing a wide range of biologically active compounds with potential antibacterial properties. Extracts from green, brown and red seaweeds have demonstrated activity against several bacterial pathogens relevant to aquaculture, including Aeromonas, Vibrio and Pseudomonas species.

The antibacterial activity of seaweed extracts depends on species, chemical composition, extraction solvent, concentration, environmental conditions and target bacteria. Phenolic compounds, phlorotannins, sulphated polysaccharides, fatty acids and other secondary metabolites may contribute to the observed activity.Seaweed-derived antibacterial compounds have potential as components of sustainable aquaculture health-management strategies. Nevertheless, promising laboratory results must be supported by detailed chemical characterization, toxicity studies, standardized extraction methods and in vivo evaluation.

With continued research, seaweed biotechnology may contribute to the development of natural products for disease prevention and management while supporting the broader goal of responsible and sustainable aquaculture.

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Volume: 06 Issue No: 10

BIOACTIVE POTENTIAL OF POMEGRANATE, CITRUS AND APPLE PEELS FOR FUNCTIONAL BEVERAGE DEVELOPMENT: A FOCUS ON GLYCEMIC HEALTH

Article ID: AG-VO6-I10-07

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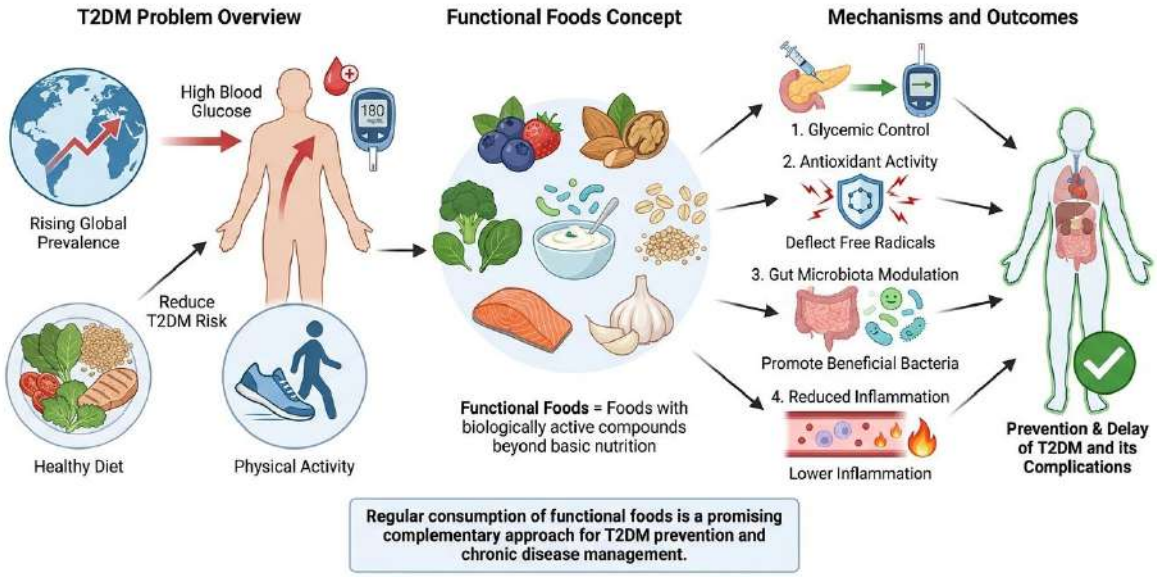
1. Introduction

There are significant amounts of waste generated during the growing, processing, distribution, and preparation processes for fruits and vegetables. Due to their high moisture content and rapid rate of bio-degradability, fruit and vegetable residues decompose quickly, especially in open markets or municipal landfills. Its improper accumulation and management may lead to the pollution of the environment and its use could be a health risk (Omre et al., 2018). India is a leading country in the production of fruits in the world as per the latest estimates of horticultural production by Government of India, the production of fruits in India has reached around 117.65 million tonnes in 2024-25. Such large amounts of waste biomass indicate the importance of implementing efficient waste management practices and establishing value added products derived from fruit and vegetable waste.

2. Diabetes Mellitus and Functional Foods

Type 2 diabetes mellitus (T2DM) is a rising global epidemic and effective prevention and management strategies are important. Lifestyle changes, especially diet and exercise, have been demonstrated to decrease the likelihood of developing T2DM in those who are at high risk. This has spurred interest in examining the protective effects of healthy food and nutrients. The term “functional foods” is used to describe foods that contain biologically active components which may have potential health benefits beyond their nutritional value. Regular intake of functional food has been shown to have a potential role in the prevention or delay of T2DM and its related complications, which involves the modulation of glycemic control, antioxidant activity, gut

microbiota and inflammatory response. Accordingly, functional foods have been a growing interest as an adjunct to health promotion and disease prevention and management of chronic



diseases like T2DM.

Fig1: Functional Foods in the Prevention and Management of Type 2 Diabetes Mellitus (T2DM)

3. Fruit Peels as Sources of Bioactive Compounds

The fruit peels are getting more and more explored as sources of bioactive compounds which can have application in glycemic health. Fruit extracts have also been shown to contain α-amylase and α-glucosidase inhibitory activity in various fruits such as pomegranate, citrus and apple (Papoutsis et al., 2021). Citrus and apple peels are also rich in several bioactive compounds that have been studied as inhibitory enzymes of carbohydrate-digesting enzymes and antioxidants and are also rich in polyphenols, tannins and flavonoids, which are studied as antioxidants and for their ability to inhibit carbohydrate-digesting enzymes. According to these results, fruit peels produced during processing could be used as a source of bioactive compounds for the production of functional products (foods and beverages). The potential use of their valorization as a way to integrate food-waste valorization and a functional product for glycemic health could then be explored (Sha et al., 2023). The recent studies have shown that the by-products of fruits peels can successfully be used in functional beverages, such as herbal teas and other beverages, without losing its antioxidant and phytochemical properties. The fruit-peel based tea formulations prepared using pomegranate, orange, apple and other fruit peels have

been reported to have measurable phytochemical content, antioxidant activity, and acceptable sensory properties, which suggests its potential as value added beverages from food-processing by-products. The production of such drinks offers a means of utilizing the fruit-processing wastes as valuable food products and promotes sustainable use of food by-products.

4. Bioactive Potential of Pomegranate, Citrus and Apple Peels

Table 1: Bioactive compounds and reported biological activities of pomegranate, Orange and apple peels

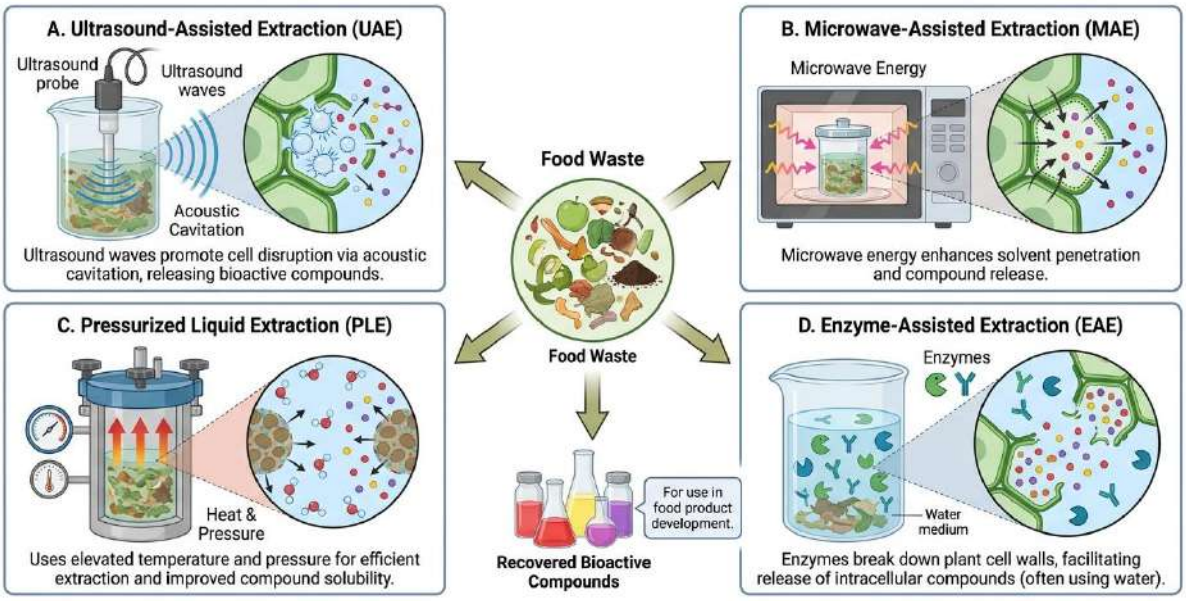
Fruit peel	Important bioactive compounds	Anti-inflammatory activity	Potential role in insulin resistance / glycemic regulation
Pomegranate peel	Gallic acid, ellagic acid, punicalagin, catechin, cyanidin	Inhibition of COX-2, IL-6, TNF-α and iNOS; modulation of NF-κB/MMP pathways	Decreased hepatic gluconeogenesis and enhanced glycogenesis; protection of pancreatic β-cells reported in diabetic models. (Sha et al., 2023)
Citrus (Orange) peel	p-Coumaric acid, nobiletin, tangeretin, ascorbic acid, hesperidin	Inhibition of iNOS, NO and COX-2; anti-inflammatory effects	Improved glucose tolerance and increased insulin action reported in experimental models. (Sha et al., 2023)
Apple peel	Epicatechin, quercetin glycosides, chlorogenic acid, phloridzin, phloretin	Reduction of inflammatory mediators such as TNF-α and IL-6 reported in experimental studies	Improved insulin sensitivity and glucose uptake; increased GLUT4 translocation through PI3K and PPAR-γ signalling (Manzano et al., 2016).

5. Extraction of Bioactive Compounds from Fruit Peels

Food waste can be used to recover valuable bioactive compounds efficiently using modern extraction techniques, and when applying solvents, use less solvent while using them.

These recovered compounds can then be used to develop nutritious, functional, and value-added food products (Pérez-Marroquín et al., 2023).

Fig 2: Different Extraction Methods of Bioactive Compounds from Fruit Peels



6. Beverage Applications of Fruit Peels

6.1 Functional Tea

Fruit peels are increasingly being explored as useful ingredients for functional beverages because they contain various bioactive compounds. Giri et al., (2025) developed herbal tea formulations using fruit peel by products and evaluated their phytochemical content, antioxidant activity and sensory acceptability. A pomegranate, apple peel formulation showed measurable phytochemical content and antioxidant activity, supporting the feasibility of using fruit peels in value-added tea preparations. However, the study did not investigate a combination of pomegranate, citrus and apple peels. This provides an opportunity to explore these three peels together, particularly for their bioactive composition and potential relevance to glycemic health. (Dewan et al., 2024)

6.2 Functional Drink

Selahvarzi et al. (2022) explored the potential of pomegranate and orange peels as sources of phenolic compounds for functional beverage development. The study optimized ultrasound-assisted extraction conditions for recovering phenolic compounds from pomegranate peel (PPE) and orange peel (OPE), and the optimized extracts were subsequently used to enrich a functional drink. The resulting beverage showed good phenolic content and antioxidant activity,

highlighting the potential of these fruit-peel by-products for developing value-added functional beverages. The findings demonstrate the feasibility of using pomegranate and orange-peel extracts in functional beverage development and provide a basis for considering additional peel combinations.

6.3 Fermented Functional Beverage

Fermentation has also been explored for the utilization of citrus peel by-products in beverage development. Cánovas et al., (2026) developed a kombucha-like fermented beverage using orange peel by-products as an alternative substrate to conventional tea. The beverage contained bioactive flavanones, with hesperidin being the predominant compound. Although the total flavanone content decreased during fermentation, flavanones remained present in the final beverage. The study demonstrated the potential of orange peel by-products for developing innovative fermented beverages and provided an alternative approach for their valorization. Since citrus peel flavanones have also been investigated for their potential role in glucose metabolism, such fermented beverages may be of interest for future research related to glycemic health. However, the beverage developed in this study was not specifically evaluated for antidiabetic effects.

7. Research Gap

While there have been studies on pomegranate, citrus and apple peels separately and as parts of various beverage combinations, most of the pomegranate peel studies have been conducted on specific peel combinations or peel applications. Pomegranate apple peel has been studied as a tea and pomegranate and orange-peel extracts have been studied in a functional lemonade beverage. Orange peel has recently been studied in a fermented beverage. The multiple application of pomegranate, citrus and apple peels in a single non-alcoholic drink, however, has not been thoroughly investigated, specifically the inhibition of α-amylase and α-glucosidase (Giri et al., 2025; Selahvarzi et al., 2022; Cánovas et al., 2026).

8. Future Perspectives

Further research can explore the combined use of pomegranate, citrus and apple peels in a single beverage. Attention should be given to selecting suitable peel proportions and extraction conditions so that the bioactive compounds are effectively recovered without compromising taste and overall beverage quality. The resulting beverage can then be studied for its phenolic and flavonoid content, antioxidant activity and α-amylase and α-glucosidase inhibitory potential.

Studies on storage stability, sensory acceptance and biological activity would also be useful for understanding its practical potential as a functional beverage for glycemic health

Conclusion

Fruit peels are increasingly recognized as valuable sources of bioactive compounds rather than simply food-processing waste. Pomegranate, citrus and apple peels contain diverse phenolic and flavonoid compounds and have been investigated for antioxidant and glycemic-related activities. Studies on tea, functional drinks and fermented beverages further demonstrate the potential of fruit peels for value-added beverage development (Giri et al., 2025; Selahvarzi et al., 2022; Cánovas et al., 2026). Overall, the available literature supports the potential of these peels for functional beverage applications, while further research is needed to understand the effects of combining pomegranate, citrus and apple peels in a single beverage and to establish its biological relevance to glycemic health.

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Volume: 06 Issue No: 10

DYNAMICS OF FRUIT GROWTH AND DEVELOPMENT IN KIWI UNDER WET TEMPERATE CONDITIONS OF UTTARAKHAND

Article ID: AG-VO6-I10-08

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Abstract

Kiwifruit (*Actinidia chinensis* Planch.) is an important high-value temperate fruit crop known for its distinctive flavour, nutritional richness and increasing market demand. Uttarakhand, with its diverse altitude and wet temperate agro-climatic conditions, offers considerable potential for kiwifruit cultivation. However, fruit growth and development are highly influenced by environmental conditions and orchard management practices. This article provides an overview of the dynamics of kiwifruit fruit growth and development under the wet temperate conditions of Uttarakhand, with emphasis on phenology, fruit set, growth stages and environmental influences. The development of kiwifruit involves sequential changes in fruit size, weight, volume, shape, firmness and dry matter accumulation from fruit set to maturity. Temperature plays a major role in regulating bud break, flowering and fruit development, while adequate chilling is essential for uniform dormancy release. Rainfall, relative humidity, light availability and soil moisture further influence pollination, fruit growth, carbohydrate accumulation and fruit quality. Excessive rainfall and humidity may increase disease pressure and affect pollination, whereas moisture stress can restrict fruit enlargement. Understanding these interactions is essential for improving cultivar selection and orchard management under local conditions. Appropriate pollination management, irrigation, drainage, nutrition, canopy management and crop-load regulation can contribute to better fruit development and quality. Overall, systematic understanding of fruit

growth dynamics under Uttarakhand's wet temperate conditions can support sustainable kiwifruit production and help realize the crop's economic potential in the Himalayan region.

Keywords: *Actinidia chinensis*, fruit growth, fruit development, wet temperate conditions, Uttarakhand, fruit quality, phenology.

Introduction

Kiwi (*Actinidia* spp.) is a temperate fruit crop belonging to the family Actinidiaceae. It is a deciduous, perennial, woody climbing vine that is valued for its attractive appearance, distinctive fruit flavour and high nutritional properties. The crop is native to China and it is traditionally known as the Chinese gooseberry, and was later commercialized extensively in New Zealand, from which the name "kiwifruit" originated. At present, kiwifruit is cultivated in several temperate and subtropical regions of the world, including China, New Zealand, Italy, Chile, Greece, Iran and India.

The commercially important kiwifruit is mainly represented by *Actinidia chinensis* var. *deliciosa* and *Actinidia chinensis*. Green-fleshed cultivars such as 'Hayward' are widely grown, while yellow-fleshed and other coloured cultivars have also gained importance in recent years. Kiwifruit is generally dioecious, meaning that male and female flowers occur on separate plants. Therefore, adequate pollination through suitable male pollinizers is essential for successful fruit set and the development of marketable fruits. Kiwifruit is considered a highly nutritious fruit because it contains considerable amounts of vitamin C, dietary fibre, sugars, organic acids, minerals, phenolic compounds and other bioactive substances. Regular consumption of kiwifruit has been associated with antioxidant and nutritional benefits, making it an increasingly valuable fruit in the health-conscious market. The fruit is consumed mainly as fresh fruit, although it is also used in juices, desserts, salads, processed products and other value-added products.

In India, kiwifruit cultivation has expanded particularly in the Himalayan regions because of the availability of suitable temperate climatic conditions. Uttarakhand possesses considerable potential for kiwifruit production due to its diverse altitudinal ranges and favourable agro-climatic conditions. The wet temperate regions of the state provide suitable environmental conditions for growth and development of kiwifruit; however, variations in temperature, rainfall, humidity and soil moisture can considerably influence flowering, fruit set, fruit growth and maturity. Therefore, studying the dynamics of fruit growth and development under the specific environmental conditions of Uttarakhand is essential for improving productivity, fruit quality and

orchard management. A better understanding of the relationship between environmental conditions and different stages of fruit development can help in identifying suitable cultivars, optimizing cultural practices and predicting harvest maturity. Such information is particularly valuable for the sustainable expansion of kiwifruit cultivation in the wet temperate regions of Uttarakhand.

Botanical and Pomological Characteristics of Kiwi

Kiwifruit is a deciduous, perennial, woody fruit crop belonging to the genus *Actinidia* and family Actinidiaceae. It is a vigorous climbing vine that requires a strong support system for proper growth and fruit production. The crop is valued for its distinctive fruit characteristics, attractive flavour and high nutritional value. Commercial kiwifruit production is mainly based on *Actinidia chinensis* var. *deliciosa* and *Actinidia chinensis*. The vines are generally dioecious, with male and female flowers borne on separate plants, making effective pollination an important factor for commercial fruit production.



Plate 1: Habitat of Kiwi plant

Taxonomy and Botanical Description

The taxonomic classification of commercially cultivated kiwifruit is generally given as follows:

Taxonomic Rank	Classification
Kingdom	Plantae
Division	Angiospermae

Taxonomic Rank	Classification
Class	Eudicots
Order	Ericales
Family	Actinidiaceae
Genus	*Actinidia*
Species	*Actinidia chinensis* Planch.

Kiwifruit is dioecious, with male and female flowers occurring on separate vines. Flowers are generally borne in the axils of current-season shoots. Female flowers contain well-developed ovaries and numerous stamens, although the stamens are generally non-functional in fruit production. Male flowers possess numerous functional stamens but lack a functional ovary. Pollination is mainly carried out by insects, particularly honey bees, and adequate pollen availability is essential for obtaining good fruit size and shape.

The fruit is a berry with a characteristic brown, hairy or relatively smooth skin depending on the species and cultivar. The flesh may be green, yellow or other colours and contains numerous small black seeds arranged around the central core. Fruit size, shape, flesh colour, firmness, soluble solids and acidity vary considerably among cultivars.

Origin and Distribution

Kiwifruit originated in China, particularly in the mountainous regions of central and eastern China. Seeds of *Actinidia* were introduced from China to New Zealand during the early twentieth century, where systematic selection and cultivation led to the development of improved commercial types. New Zealand played a major role in the international commercialization and development of kiwifruit as a commercial fruit crop.

At present, China is one of the major producers of kiwifruit, while important commercial production also occurs in New Zealand, Italy, Chile, Greece, Iran and other temperate countries. In India, kiwifruit cultivation has gained importance mainly in the Himalayan regions, particularly in Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh and parts of northeastern hill regions.

Major Commercial Cultivars

Several kiwifruit cultivars are cultivated commercially, differing in fruit size, shape, skin characteristics, flesh colour, maturity period, flavour and storage ability. Among green-fleshed

kiwifruits, **'Hayward'** is one of the most widely cultivated and commercially important cultivars. It produces large, oval to oblong fruits with brown, hairy skin and green flesh containing numerous small black seeds. The cultivar is valued for its attractive fruit appearance, flavour, firmness and excellent storage potential. Other commercially important green-fleshed cultivars include **'Bruno', 'Abbott', 'Monty'** and **'Allison'**. Yellow-fleshed kiwifruit types have also become increasingly important because of their attractive colour, sweeter flavour and consumer preference. Cultivars belonging to *A. chinensis* include several yellow-fleshed selections with differences in fruit quality and maturity period.

Climatic and Soil Requirements

Kiwifruit performs best under temperate climatic conditions with adequate winter chilling followed by a relatively warm and frost-free growing season. The crop requires sufficient chilling during winter for satisfactory bud break and subsequent flowering. However, excessive exposure to extremely low temperatures can damage vines and developing buds. Similarly, late spring frost can adversely affect newly emerged shoots and flowers.

Importance and Production Potential

Kiwifruit has emerged as a promising high-value temperate fruit crop in Uttarakhand due to its nutritional value, good market demand and suitability to the state's hill agro-climatic conditions. The crop offers an opportunity for diversification from traditional fruit crops and can provide better returns to farmers when suitable cultivars and proper orchard management practices are adopted. The availability of varied altitudes and temperate production zones gives Uttarakhand considerable potential for expanding kiwifruit cultivation.

Suitability of Wet Temperate Regions

The wet temperate regions of Uttarakhand provide favourable conditions for kiwifruit growth, particularly where adequate winter chilling, moderate summer temperatures and sufficient moisture are available. The cool climate and well-drained hill soils can support satisfactory vegetative growth, flowering, fruit set and fruit development. However, proper site selection and drainage are essential in high-rainfall areas to avoid waterlogging and excessive humidity.

Major Constraints in Kiwi Production

Despite its potential, kiwifruit production in Uttarakhand faces several constraints, including irregular rainfall, extreme weather events, late spring frost, inadequate pollination,

poor orchard management and insufficient availability of quality planting material. Excessive rainfall and humidity may also favour disease development, while inadequate irrigation during dry periods can affect fruit growth. Lack of scientific knowledge, suitable training and pruning practices, and limited post-harvest and marketing facilities are additional challenges affecting commercial production.

Phenology and Fruit Set in Kiwi

Phenology of kiwifruit refers to the sequence and timing of important developmental events such as bud break, flowering, pollination, fruit set and fruit development. These stages are strongly influenced by cultivar, chilling accumulation, temperature, altitude, rainfall and other environmental conditions. Under the wet temperate conditions of Uttarakhand, proper synchronization of these stages is important for achieving good fruit set and uniform fruit development.

1. **Bud Break and Flowering**

After completing its winter dormancy, kiwifruit begins active growth with bud swelling and bud break during spring. Bud break is mainly influenced by the accumulation of winter chilling followed by suitable temperatures. New shoots develop from overwintered buds, and flower buds are generally borne on the current season's shoots. Flowering usually occurs during spring, although the exact period varies with cultivar, altitude and prevailing weather conditions. Adequate temperature during this stage promotes uniform flowering, whereas frost or abnormal weather may damage young shoots and flowers.



Plate 2: Bud break in Kiwi

2. Pollination and Fertilization

Kiwifruit is predominantly dioecious, with male and female flowers occurring on separate vines. Therefore, successful fruit production requires the presence of compatible male pollinizers near female vines. Pollination is mainly carried out by insects, particularly honey bees. Because kiwifruit flowers produce relatively little nectar, maintaining sufficient pollinator activity during flowering is important. After pollen reaches the stigma, pollen germination and pollen tube growth lead to fertilization. Good weather conditions during flowering, along with adequate pollen availability, are essential for successful fertilization.



Plate 3: Flowering in Kiwi

3. Fruit Set

Fruit set begins after successful pollination and fertilization and represents the transition from flower to developing fruit. The percentage of fruit set depends on pollination efficiency,

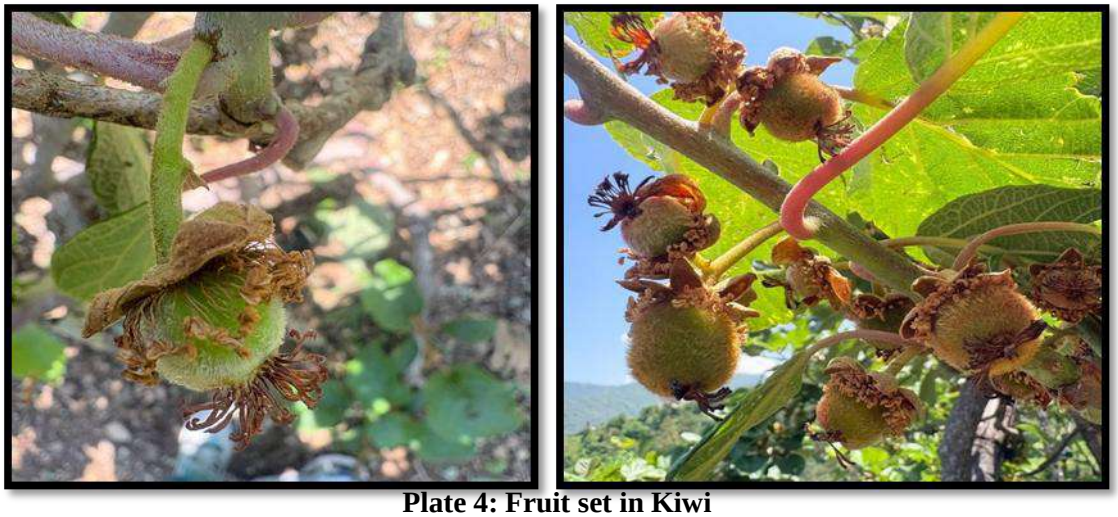


Plate 4: Fruit set in Kiwi

pollen viability, weather conditions, cultivar and the physiological condition of the vine. Adequate pollination is particularly important in kiwifruit because the number of seeds formed can influence fruit size and development. Poor pollination may result in low fruit set, smaller fruits and irregular fruit shape. Hence, proper male-to-female vine ratio and effective pollinator activity are important for obtaining a satisfactory crop.

4. Early Fruit Development

Following fruit set, young kiwifruit undergoes rapid growth through cell division and cell enlargement. During the early stage, fruit size and weight increase progressively, while developing seeds and surrounding tissues act as important sinks for assimilates. Adequate availability of water, nutrients and photosynthates is necessary during this period.

The early fruit-development stage is particularly sensitive to environmental fluctuations, and moisture stress, excessive rainfall or inadequate nutrition can adversely affect fruit growth. Proper irrigation, nutrition, canopy management and crop-load regulation during this stage help in achieving better fruit size and uniform development.

Dynamics of Fruit Growth and Development

Fruit growth and development in kiwifruit is a continuous and dynamic process involving changes in fruit size, weight, volume, shape, firmness and dry matter. These changes are influenced by cultivar, crop load, environmental conditions, water availability and nutritional status.



Plate 5: Fruit growth in Kiwi

1. **Stages of Fruit Growth**

Kiwifruit growth can broadly be divided into three phases: **early rapid growth, intermediate growth and late maturation**. The early stage is mainly characterized by active cell division, followed by cell enlargement and accumulation of carbohydrates. During the final stage, fruit growth slows down while dry matter and soluble solids continue to increase.

2. **Fruit Growth Pattern**

Fruit growth generally follows a **double-sigmoid growth curve pattern**, although the duration and intensity of different phases may vary among cultivars and growing conditions. Rapid growth occurs during the early and later stages, with a comparatively slower phase in between. Temperature, moisture, crop load and cultivar strongly influence the rate of fruit growth.

3. **Changes in Fruit Size and Weight**

Fruit size and weight increase progressively from fruit set until maturity. The initial increase is mainly associated with cell division, followed by considerable cell enlargement. Adequate assimilate supply and optimum moisture availability are essential for achieving desirable fruit size and marketable weight.



Plate 6: Fruit shape in Kiwi

4. **Changes in Fruit Volume**

Fruit volume increases steadily as the fruit develops due to cell enlargement and accumulation of water and dry matter. The rate of increase is generally high during the active growth phase and gradually declines as the fruit approaches physiological maturity.

5. **Changes in Fruit Shape and Firmness**

Young kiwifruits undergo changes in length, diameter and overall shape during development. Fruit firmness is initially high and generally decreases as ripening progresses

because of the breakdown and modification of cell-wall components. However, mature kiwifruits retain considerable firmness compared with many other soft fruits, which contributes to their good storage potential.

Influence of Wet Temperate Conditions on Fruit Growth and Development

The growth and development of kiwifruit are strongly influenced by environmental conditions. Under the wet temperate conditions of Uttarakhand, temperature, rainfall, humidity, chilling, light and soil moisture interact to determine flowering, fruit set, fruit growth, maturity and final fruit quality.

1. **Temperature**

Temperature is one of the most important factors affecting kiwifruit growth and development. Cool winters provide the required chilling for proper dormancy release, while moderate temperatures during spring and summer favour vegetative growth, flowering and fruit development.

2. **Rainfall and Humidity**

Adequate rainfall supports vegetative growth and fruit development by maintaining soil moisture. However, excessive rainfall and high relative humidity, which are common in wet temperate regions, may lead to poor soil aeration, waterlogging and increased incidence of fungal diseases.

3. **Chilling Requirement**

Kiwifruit requires sufficient exposure to low temperatures during winter to overcome bud dormancy and ensure uniform bud break and flowering. Insufficient chilling may result in delayed or uneven bud break and poor flowering. Variations in winter temperature associated with changing climatic conditions may therefore influence the phenological behaviour and subsequent fruit production of kiwifruit.

4. **Light and Photoperiod**

Adequate sunlight is essential for photosynthesis and carbohydrate production, which directly supports fruit growth. Good light interception within the canopy promotes the accumulation of dry matter and improves fruit quality. Excessive shading due to dense canopy growth can reduce photosynthetic activity and carbohydrate supply to developing fruits. Photoperiod also contributes to the seasonal regulation of plant growth and dormancy.

5. Soil Moisture Availability

Kiwifruit has a relatively water requirement because of its vigorous growth and large leaf area. Adequate and consistent soil moisture is particularly important during flowering, fruit set and rapid fruit enlargement. Both water deficiency and excessive moisture can adversely affect fruit development. Therefore, proper drainage combined with supplemental irrigation during dry periods is important under Uttarakhand conditions.

6. Interaction of Environmental Factors with Fruit Development

Environmental factors do not act independently; their combined effects determine the overall growth and development of kiwifruit. Temperature influences phenology, while rainfall, humidity and soil moisture affect water availability and disease pressure. Light determines photosynthetic activity and assimilates production, which ultimately influences fruit size and dry matter accumulation. Thus, favourable environmental conditions and appropriate orchard management are essential for achieving optimum fruit growth and quality under the wet temperate conditions of Uttarakhand.

Conclusion

Kiwifruit is a promising high-value temperate fruit crop with considerable potential for cultivation in the wet temperate regions of Uttarakhand. Fruit growth and development is a complex and dynamic process influenced by cultivar, pollination, crop load, temperature, rainfall, humidity, light, soil moisture and nutrient availability. The progression from bud break and flowering to fruit set, enlargement, dry matter accumulation and maturity determines the final fruit size, quality and market value. The wet temperate conditions of Uttarakhand provide favourable climatic conditions for kiwifruit production; however, variations in temperature, excessive rainfall, high humidity, irregular moisture availability and climatic fluctuations can influence fruit development. Proper selection of suitable cultivars, effective pollination, balanced nutrition, adequate irrigation and drainage, canopy and crop-load management are therefore essential for achieving optimum fruit growth and quality. A better understanding of the relationship between environmental conditions and different stages of fruit development can help in improving orchard management and productivity. Therefore, systematic studies on fruit growth dynamics under the specific agro-climatic conditions of Uttarakhand are important for identifying suitable cultivars, optimizing production practices and supporting the sustainable expansion of kiwifruit cultivation in the region.

Volume: 06 Issue No: 10

FARMERS, FLOODS AND THE PSYCHOLOGICAL AFTERMATH IN NORTHEAST INDIA

Article ID: AG-VO6-I10-09

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Introduction

In Northeast India, the monsoon is never simply a season of rain. It is a time of renewal, cultivation and hope, but it can also become a season of uncertainty. Rivers fill, fields turn green and farmers prepare for another agricultural cycle. Yet when the water rises beyond what communities can absorb, the same rivers that sustain rural life can become destructive forces. The floods of 2026 once again brought this difficult reality into focus. Assam, in particular, experienced severe flooding during the monsoon, affecting villages, agricultural land, livestock and household livelihoods. Reports during the peak of the flood indicated that more than seven lakh people had been affected and around 25,375 hectares of cropland had been submerged. Nearly 1.39 lakh animals were also reported to have been affected. These figures are important, but they cannot fully describe what a flood means to a farming family. For a farmer, a flooded field is not simply a damaged piece of land. It represents months of labour, finance, investment, family savings and expectations for the future.

The Farmer's Loss Begins Before the Water Drains Away

Agriculture in Assam is closely connected with the rhythms of the Brahmaputra and its tributaries. Paddy, vegetables, pulses, livestock and fisheries support both household consumption and income. When floodwater enters a village, farmers may lose standing crops within a few days. Stored seed, fertilizer, agricultural equipment, poultry and livestock may also be damaged or lost. The 2026 flood situation in Upper Assam illustrated this vulnerability. Districts including Jorhat, Sivasagar, Charaideo, Golaghat and Dhemaji experienced significant agricultural impacts during different phases of the monsoon. Official and media reports during

the flood period recorded thousands of hectares of affected cropland across the state. The economic consequences continue after the water recedes. A farmer may have to purchase seed again, repair agricultural tools, replace livestock or borrow money to prepare the next crop. In many households, the question is not simply how to recover the lost crop, but how to finance the next season while dealing with existing debt. Floods can therefore create a cycle of vulnerability: crop loss leads to financial pressure; financial pressure reduces the ability to invest in the next season; reduced investment can lower future production; and another flood can push the household even deeper into difficulty.

The Northeast's Flood Story Is Interconnected

Although Assam often receives the greatest attention, the flood situation of the Northeast cannot be understood within state boundaries. Rivers connect Arunachal Pradesh, Assam, Meghalaya, Nagaland and other parts of the region. Heavy rainfall and landslides in upstream areas can rapidly influence downstream river systems. During 2026, episodes of flooding and landslides affected parts of Arunachal Pradesh and other Northeastern states. Agricultural land, roads and villages were affected, while water flowing downstream added to the pressure on communities in Assam. This interconnected nature of the region means that flood preparedness also needs to be interconnected. River-basin planning, early-warning systems, protection of wetlands and better coordination between states are increasingly important.

The Invisible Flood: Psychological Distress

The most visible consequences of a flood are easy to count: houses damaged, hectares submerged, livestock lost and people evacuated. The emotional consequences are much harder to see. A farmer who watches a mature crop disappear under floodwater may experience grief, helplessness and anxiety. Someone who has repeatedly lost crops may begin to associate dark clouds or rising river levels with fear. For families who have already experienced displacement, each new warning of heavy rain can reopen memories of earlier disasters.

Trauma Does Not Always End When the Flood Ends

People affected by floods may experience sleeplessness, recurring memories, irritability, sadness, fear, difficulty concentrating and a persistent feeling of insecurity. Not everyone develops a mental-health disorder, but many people can experience significant psychological distress. (World Health Organization, 2025). Farmers may face an additional burden because their livelihood depends directly on weather and environmental conditions. When the crop fails,

income can disappear at the same time that expenses increase. The farmer may have to think about food, education, medical expenses, loan repayment and the cost of starting another crop. A 2026 systematic review and meta-analysis of studies involving Indian flood survivors reported a high pooled prevalence of post-traumatic stress disorder. The researchers also noted considerable variation between studies, meaning that the figure should not be treated as a universal rate for every flood-affected community. Nevertheless, the evidence reinforces the need to include mental health in disaster preparedness and recovery (Kappan & Thiagarajan, 2026).

Women Carry a Different Burden

Women often take responsibility for preparing food, caring for children and older family members, collecting water and maintaining household routines during displacement. When cooking facilities, drinking water and sanitation facilities are disrupted, these responsibilities can become much more difficult (Kakati et al., 2026; WHO, 2025). Women who contribute to agriculture may also lose kitchen gardens, poultry, livestock, small food-processing activities or other sources of supplementary income. For adolescent girls, flooding may interrupt schooling and create additional difficulties related to sanitation, privacy, safety and nutrition. This is why flood recovery should be gender-sensitive. Women and girls should not be viewed only as recipients of relief. Their knowledge, labour and participation are important to household and community recovery.

From Relief to Recovery

Emergency relief remains essential. Food, drinking water, medicines, temporary shelter and sanitation must reach affected families quickly. However, long-term recovery requires more than relief materials (WHO, 2025). Farmers need timely access to seeds, planting materials, livestock feed, veterinary care, agricultural tools and affordable credit. Where fields remain waterlogged or covered with sand, farmers need technical guidance on soil recovery and alternative crops. Agricultural extension agencies and Krishi Vigyan Kendras can play an important role by promoting flood-resilient practices, suitable short-duration crops, crop diversification and locally appropriate livelihood options. Nutrition gardens and kitchen gardens can help families regain access to vegetables and improve household nutrition. Poultry, fisheries, livestock and small-scale food processing can provide additional sources of income when crop recovery is slow (Hazarika et al., 2026). Mental health support should be integrated into this recovery process rather than treated as a separate issue. Community-level workers, teachers,

ASHA workers, Anganwadi workers, extension personnel and local volunteers can be trained to recognise signs of severe distress and provide basic psychological first aid. People experiencing persistent symptoms or serious mental-health difficulties should be referred to qualified professionals (WHO, 2025).

Building a More Resilient Rural Northeast

The floods of 2026 should encourage the Northeast to rethink what flood resilience really means. The objective cannot simply be to prevent every flood. Floods are part of the natural river system, and seasonal flooding can also support wetlands and ecosystems. The greater challenge is to reduce destructive impacts while helping communities live more safely with rivers (Hazarika et al., 2026). Early-warning information must reach farmers in villages in a form that is clear and actionable. Evacuation plans should consider not only people but also livestock, seed, agricultural equipment and important household documents. Local shelters need adequate water, sanitation, food and privacy, particularly for women, children and older persons (WHO, 2025). At the same time, wetlands and natural drainage systems need protection. Riverbank erosion and land-use changes should be addressed through long-term planning. Farmers need access to climate-resilient agricultural technologies, weather information and diversified livelihood opportunities (Hazarika et al., 2026). Perhaps most importantly, disaster planning should recognise that recovery has both a physical and emotional dimension.

The Road after the Water

For a farmer, the end of a flood is not necessarily the end of the disaster. The real struggle begins when the farmer walks back into a field and sees the damaged crop. It may begin when a family calculates the cost of repairing its house, replacing livestock or buying seed for the next season. It may continue when every dark cloud creates a quiet fear that the river might rise again. A farmer may receive seed and still feel anxious. A family may receive food and still be grieving. A field may dry out while the memory of losing a livelihood remains. True flood resilience therefore needs to include resilient agriculture, livelihood diversification, social protection, women's participation, early warning, community preparedness and accessible mental-health support. When the waters recede, recovery should ask more than how many hectares were damaged. It should also ask whether farmers have the resources to plant again, whether families feel safe enough to rebuild, and whether people have received the emotional support needed to move forward. The future of the rural Northeast depends not only on

protecting its fields from water, but also on protecting the people whose lives and hopes are rooted in those fields.

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Volume: 06 Issue No: 10

PROTECTING HONEY BEES: PREVENTION AND MANAGEMENT OF MAJOR PESTS AND DISEASES

Article ID: AG-VO6-I10-10

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Introduction

Honey bees are among the most valuable insects in agriculture and rural livelihoods. Besides producing honey, wax, pollen, propolis, royal jelly and bee venom, they provide an essential ecosystem service through pollination. Fruit crops, vegetables, oilseeds, spices, plantation crops and many wild plants benefit directly or indirectly from bee pollination. Therefore, the health of honey bee colonies is closely connected not only with honey production but also with crop productivity, biodiversity and farm income.

However, honey bee colonies are living biological units that can be weakened by insect pests, parasitic mites, bacterial diseases, fungal diseases, microsporidian infections, viruses, poor

nutrition, pesticide exposure and unsuitable management. In most situations, colony losses do not result from a single cause. A weak colony may suffer from poor queen performance, reduced pollen availability, heavy mite infestation, viral infection and wax moth attack at the same time. Hence, successful bee health management must be based on prevention, early diagnosis, strong colony maintenance, sanitation, biosecurity and careful use of approved treatments.



Figure 1. A healthy honey bee brood frame normally shows a compact brood pattern, active worker bees and sufficient food reserves.

Importance of Honey Bee Health

A honey bee colony functions as a superorganism. The queen, workers, drones, brood and food stores are all interdependent. When the colony is strong, workers can forage efficiently, regulate nest temperature, feed larvae, defend the hive and remove diseased brood or invading pests. In contrast, when the colony becomes weak, its natural defence mechanisms decline. Weak colonies are more vulnerable to wax moths, small hive beetles, robbing, ants, wasps and disease outbreaks.

Healthy colonies also produce better-quality honey and other hive products. Diseased colonies may yield less honey, show poor brood development, have low adult-bee population and become unsuitable for migration or pollination services. Beekeepers must therefore treat colony health as a routine production activity, similar to irrigation, fertilization and pest

management in crop cultivation. Good beekeeping practices are the first line of defence. FAO guidance emphasizes maintaining colony strength, preventing robbing, cleaning and disinfecting equipment, replacing old combs, avoiding the transfer of contaminated hive materials and detecting disease early through regular inspection.

Causes of Colony Weakness

Honey bee diseases and pests become severe when colonies are exposed to one or more stress factors. The most common causes include poor queen quality, shortage of pollen and nectar, overcrowding, excessive empty hive space, moisture inside the hive, poor ventilation, old combs, pesticide exposure, contaminated equipment and movement of colonies without health checks. A failing queen leads to irregular brood production and poor colony population. When the worker population is low, bees cannot adequately cover brood or protect combs. This creates favourable conditions for wax moth infestation, chilling of brood, beetle invasion and robbing by neighbouring colonies. Similarly, colonies kept in damp and poorly drained locations may experience chalkbrood, Nosema infection and general weakness.

Nutritional stress is another major factor. Honey bees require carbohydrates from nectar or honey, proteins and lipids from pollen, minerals, water and other micronutrients. During drought, prolonged rainfall, winter, migration or periods of low flowering, colonies may face starvation or protein deficiency. Under such conditions, brood rearing declines, adult longevity reduces and diseases become more serious. Proper colony nutrition is therefore a disease-prevention tool as well as a productivity measure.

Regular Colony Inspection

Regular inspection is essential for early detection of pests and diseases. A beekeeper should inspect colonies at suitable intervals depending on season, colony condition and local pest pressure. Frequent disturbance should be avoided during the main honey flow, cold weather or heavy rains, but colonies must still be observed externally for signs of abnormality.

During inspection, the beekeeper should examine the queen's presence, brood pattern, number of adult bees, pollen stores, honey stores, comb condition, presence of pests, signs of disease and general hive cleanliness. A healthy brood pattern is usually compact and uniform, with relatively few empty cells among sealed brood. A spotty brood pattern may indicate queen failure, brood disease, chilling, mite infestation or nutritional stress.

The bottom board should also be examined for dead bees, wax moth larvae, beetle larvae, faecal streaks, chalkbrood mummies and mite fall. The hive entrance provides useful information. Crawling bees, bees with malformed wings, dead larvae, foul smell, excessive fighting, robbing activity or unusual bee behaviour should alert the beekeeper to investigate further.

Wax Moth: A Serious Pest of Weak Colonies

Wax moths are among the most familiar pests of honey bee colonies and stored combs. The greater wax moth, *Galleria mellonella*, is more damaging than the lesser wax moth, *Achroia grisella*. The adult moth itself does not cause major damage; the destructive stage is the larva. Wax moth larvae feed mainly on wax residues, pollen, shed larval skins, cocoons and debris present in old brood combs. Wax moth infestation is most severe in weak colonies, queenless colonies, abandoned hives and improperly stored combs. Strong colonies normally control wax moth eggs and young larvae through cleaning and removal behaviour. When colony population declines, however, adult bees cannot protect all comb surfaces. The larvae then tunnel through combs, form silken webbing and destroy the comb structure.

Early symptoms of wax moth infestation include thin silk threads on combs, small tunnels, faecal pellets and larvae hidden beneath webbing. In severe infestation, the entire comb may become covered with silk, riddled with tunnels and unsuitable for brood rearing or honey storage. Mature wax moth larvae may also damage wooden hive parts by forming pupation sites in cracks, corners and hive walls. The best management strategy is to maintain strong colonies. Weak colonies should not be allowed to remain weak for long periods. They should be united with another colony, requeened or reduced to a smaller hive space that can be covered by available adult bees. Old, blackened and damaged brood combs should be replaced regularly because they contain more cocoons and residues that attract wax moth larvae.

Stored combs require special care. Honey extractors, supers and unused combs should never be left exposed in the apiary. Drawn combs should be stored in dry, well-ventilated and pest-proof rooms. Where facilities are available, freezing combs can kill wax moth eggs, larvae and pupae. Periodic inspection of stored combs is important because early infestations can be managed before extensive damage occurs.



Figure 2. Wax moth larvae produce webbing, tunnels and faecal pellets while feeding inside honey bee combs.

Small Hive Beetle

The small hive beetle, *Aethina tumida*, is a damaging pest of honey bee colonies in areas where it has become established. Adult beetles enter the hive and hide in cracks, beneath the cover, around the brood nest and in corners where bees cannot easily remove them. Female beetles lay eggs in crevices and combs. The larvae are the most destructive stage because they feed on pollen, honey, brood and wax residues.



***Figure 3. The small hive beetle, Aethina tumida,* can multiply rapidly in weak or poorly managed colonies.**

The most characteristic sign of heavy infestation is fermented, slimy honey. Beetle larvae feed in honey combs and contaminate honey with excreta and microorganisms. The honey may become frothy, sour-smelling and unsuitable for consumption. In severe cases, the colony may abscond because it cannot tolerate the infestation. Management begins with colony strength. Small hive beetles are more likely to establish in queenless, weak or stressed colonies. Beekeepers should avoid excessive empty space in hives and should promptly unite colonies that cannot maintain an adequate adult-bee population. Regular cleaning of bottom boards, removal of debris and maintenance of hygienic extraction rooms reduce breeding sites.

Beetle traps can help monitor and suppress adult beetles. Honey supers should be extracted promptly after removal from colonies. Wet combs, pollen combs and honey residues should not be left exposed because they attract beetles and permit larval development. Strict sanitation during honey extraction is especially important. FAO practical guidance identifies strong colonies, good apiary hygiene and appropriate trapping as central measures for small hive beetle management.

Ants, Wasps and Hornets

Ants often enter hives in search of honey, sugar syrup, pollen, wax debris and dead bees. Although a few ants may not cause serious damage, large colonies of ants can disturb bees, rob food stores and weaken small colonies. Ant problems are more common when hives are placed directly on the ground or when weeds, branches and supporting structures form pathways to the hive. Bee colonies can be protected by placing hives on stands and using barriers such as grease, oil or water moats on stand legs where practical. Vegetation around hive stands should be cleared regularly. The beekeeper should ensure that no branches, ropes or nearby objects form a bridge between the ground and the hive. Wasps and hornets are active predators of honey bees. They capture foraging bees, attack hive entrances and may rob honey from weak colonies. Their impact is generally more serious during seasons of low nectar flow, when colonies are weak or when predator populations are high. Entrance reducers may help colonies defend themselves, but ventilation must be maintained. Strong colonies are much better able to resist wasp and hornet attacks than weak colonies.

Varroa Mite: The Most Important Parasitic Threat

The parasitic mite *Varroa destructor* is one of the most serious pests of managed honey bee colonies, particularly *Apis mellifera*. The adult female mite is reddish brown, flattened and

visible to the naked eye. It feeds on developing brood and adult bees and reproduces inside sealed brood cells. The mite has a preference for drone brood because drone cells remain capped longer and provide more time for mite reproduction.

Varroa infestation is dangerous not only because mites weaken bees directly, but also because mites spread and intensify viral infections. Deformed wing virus is commonly associated with severe varroa infestation. Affected bees may emerge with crumpled wings, shortened abdomens, reduced body weight and poor flight ability. Such bees cannot forage effectively and often die near the hive entrance. In the early stages, varroa infestation may not be obvious. Therefore, beekeepers should not wait until deformed wings are observed. Regular monitoring is necessary. Common monitoring methods include alcohol wash, soap wash, sugar shake, drone brood uncapping and sticky-board examination. Among these, alcohol or soap wash methods are generally considered useful for estimating mite infestation in a representative sample of adult bees. The purpose of monitoring is to determine whether mite population is increasing and whether management measures are needed. Calendar-based treatment without monitoring may lead to unnecessary chemical use, residues in bee products and development of acaricide resistance. After treatment, mite levels should be checked again to confirm that the intervention was effective. USDA honey-bee research identifies *Varroa destructor* as a major threat to colony health because of its direct parasitic effect and its role in virus transmission.

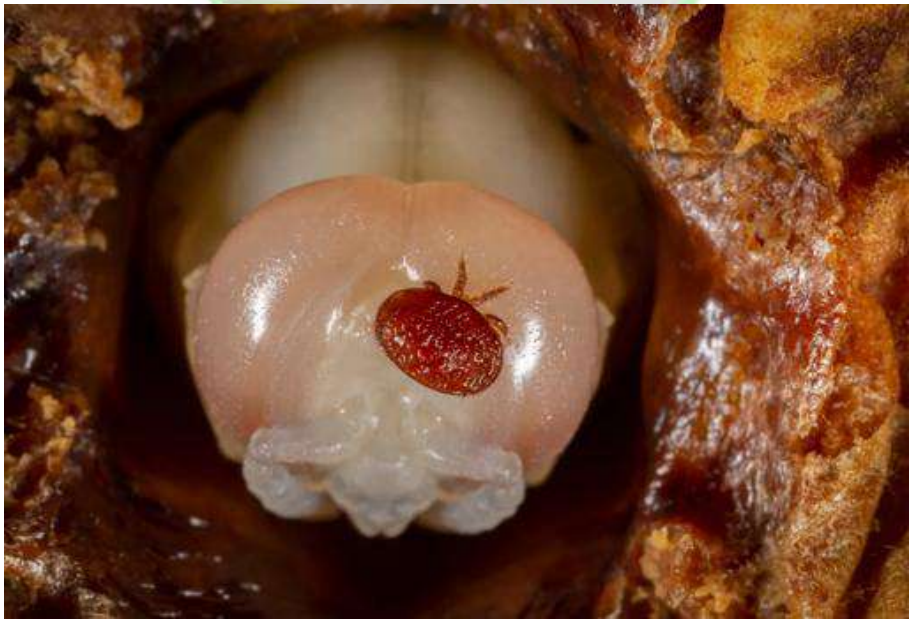


Figure 4. Adult female Varroa destructor mite attached to a honey bee.

Integrated Varroa Management

Varroa management should follow an integrated approach. The beekeeper should first monitor infestation, assess colony strength and then decide on an appropriate control strategy. A combination of cultural, mechanical, genetic and chemical methods is more sustainable than relying only on one acaricide. Cultural management includes maintaining young queens, ensuring good nutrition, avoiding prolonged weak-colony conditions and reducing reinfestation from neglected colonies. Drone brood removal can be used as a supportive method because varroa mites reproduce more successfully in drone cells. However, drone brood removal alone is not sufficient where mite populations are already high. Mechanical measures such as screened bottom boards may contribute to mite reduction by preventing fallen mites from returning to the colony. However, these methods should be considered supportive rather than complete control measures. Research has also examined physical barriers that prevent fallen mites from re-entering colonies.

Chemical control must be used carefully. Only registered and approved bee-safe products should be used, and label instructions must be followed exactly. The beekeeper must consider dose, temperature, brood condition, honey-flow period and harvest interval. Repeated use of the same chemical group can select for resistant mite populations. Therefore, rotation of acaricide groups and periodic assessment of treatment effectiveness are important.

American Foulbrood

American foulbrood, commonly known as AFB, is one of the most destructive bacterial brood diseases of honey bees. It is caused by *Paenibacillus larvae*, a spore-forming bacterium. The disease affects larvae after they consume spores present in contaminated brood food. The spores are extremely persistent and may survive for years in old combs, honey, hive equipment and contaminated materials. The first visible sign of AFB is often an irregular brood pattern. Healthy sealed brood cells are usually uniform and slightly raised. In an affected colony, cappings become sunken, darkened and perforated. When a suspected dead larva is gently tested with a small stick, the remains may stretch into a sticky thread or “rope.” Later, the dead larval remains dry into hard scales attached tightly to the lower cell wall.

AFB can spread through robbing, drifting bees, exchange of brood combs, movement of infected colonies, contaminated honey, used equipment and careless handling of hive materials. Feeding honey from unknown sources is especially risky because honey may contain disease

spores even when it appears normal. The most important management practice is prevention. Beekeepers should avoid exchanging combs among colonies unless health status is known. New colonies, purchased queens, used hive boxes and second-hand combs should be carefully inspected before introduction. Suspected colonies should be isolated immediately to prevent robbing and movement of contaminated material.

Laboratory confirmation is highly desirable because some brood diseases may show similar symptoms. In areas where AFB is regulated, beekeepers must follow official veterinary or apiary-health guidelines for destruction, disinfection or disposal of infected colonies and equipment. Antibiotics should not be used casually because they may mask symptoms without eliminating spores and can leave residues in honey. Regular renewal of old combs, cleaning of equipment and prevention of robbing are important elements of foulbrood prevention.

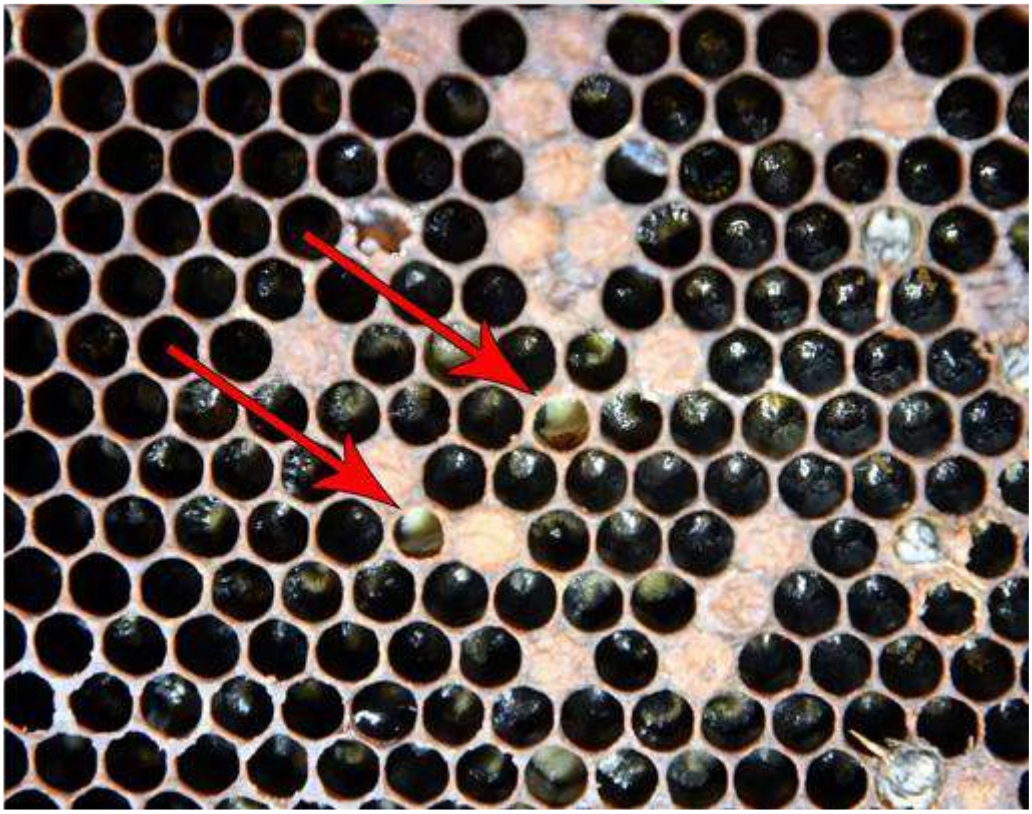


Figure 5. American foulbrood is characterized by irregular brood, sunken cappings and dead larval remains in affected cells.

European Foulbrood

European foulbrood is another important bacterial disease of honey bee brood. It is primarily caused by *Melissococcus plutonius*. Unlike American foulbrood, European foulbrood

usually affects young, unsealed larvae before the brood cells are capped. Infected larvae may appear twisted, coiled or displaced inside the cells rather than lying in their normal position. They change colour from pearly white to yellow, brown or grey. The brood pattern becomes irregular because healthy larvae and diseased larvae occur side by side. In severe cases, a sour or unpleasant odour may be noticed. European foulbrood is often associated with nutritional stress, weak colony condition, poor pollen supply, chilling of brood and other environmental pressures. Thus, management should focus on strengthening the colony. Beekeepers should ensure sufficient honey and pollen stores, reduce excessive hive space, prevent brood chilling and replace failing queens. Severely affected combs may be removed, and colonies with persistent disease problems should be evaluated for queen replacement and improved apiary conditions.

Chalkbrood Disease

Chalkbrood is a fungal disease caused by *Ascosphaera apis*. It affects honey bee larvae and is usually associated with cool, damp, poorly ventilated or nutritionally stressed colonies. After infection, larvae die and become hard, dry mummies. These mummies may be white, grey or black, depending on the fungal stage. Chalkbrood mummies can often be found at the bottom board or at the hive entrance because worker bees attempt to remove them from affected brood cells. The brood pattern may become patchy, and colony growth may slow when infestation is heavy. Management of chalkbrood is based mainly on correcting the conditions that favour the disease. Colonies should be kept strong, dry and adequately ventilated. Apiaries should be located in well-drained sites, and hives should be raised above the ground. Excessive shade and water accumulation near the apiary should be avoided. The beekeeper should also prevent brood chilling by avoiding unnecessary opening of hives during cool or rainy weather.

Replacing old combs, improving nutrition and requeening affected colonies with vigorous queens may help reduce repeated chalkbrood problems. Strong colonies can remove diseased brood more efficiently and are less likely to suffer severe disease.

Sacbrood Disease

Sacbrood is a viral disease that affects developing larvae. Infected larvae fail to pupate and become fluid-filled sacs. The larval head often turns upward, and the body changes colour from white to yellowish, brown and finally dark brown or black. When the dead larva dries, it may form a scale that can be removed relatively easily from the cell. Sacbrood can result in patchy brood and reduced colony growth. It is often more serious in weak colonies, colonies

under nutritional stress or colonies exposed to poor weather conditions. There is no simple curative treatment for viral diseases; therefore, management depends on improving colony strength and reducing stress. Affected colonies should be provided adequate nutrition, especially pollen and carbohydrate sources during dearth periods. Old or heavily affected brood combs may be removed. Requeening with healthy, productive and hygienic queens can improve colony recovery. Comb exchange from diseased colonies should be avoided to reduce spread of the virus.

Nosemosis

Nosemosis is an adult-bee disease caused by microsporidian parasites, mainly *Nosema apis* and *Nosema ceranae*. These parasites infect the digestive system of adult bees, especially the midgut. The disease can reduce adult-bee lifespan, interfere with digestion, weaken foraging activity and lead to gradual colony decline.

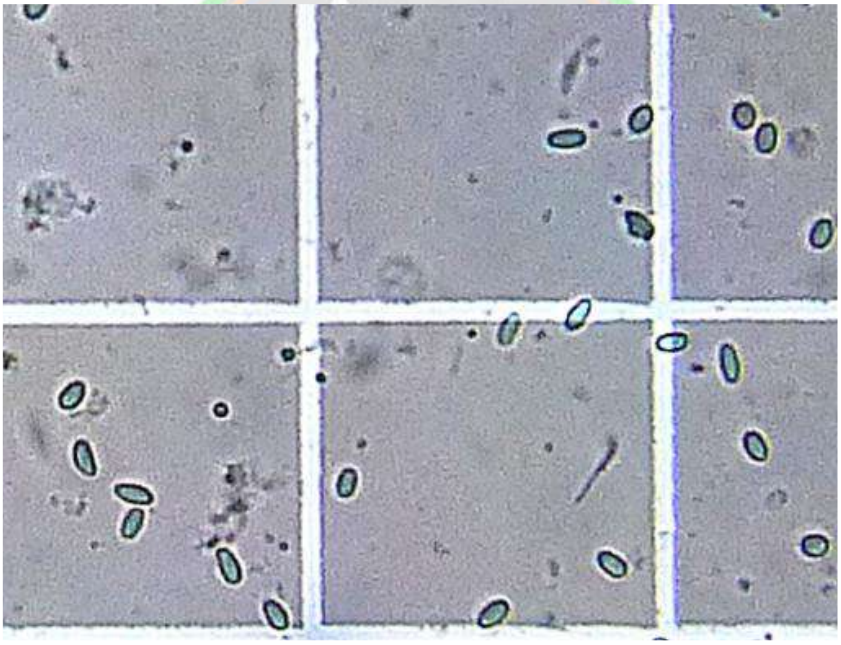


Figure 6. Nosema spores can be identified through microscopic examination of honey bee samples.

Symptoms may include weak colony growth, reduced honey production, crawling bees near the hive entrance, faecal streaking on hive parts and poor spring build-up. However, symptoms are not always clear, especially in *Nosema ceranae* infection. Confirmation through microscopic examination of adult bee samples or laboratory testing is advisable.

Nosemosis is favoured by poor nutrition, dampness, prolonged confinement, stress and unhygienic conditions. Management should therefore focus on colony nutrition, ventilation and sanitation. Colonies should have sufficient honey and pollen reserves. Bottom boards should be cleaned, and old combs should be replaced gradually. Hives should be placed in dry locations with good drainage. Requeening weak colonies, avoiding transfer of combs from poorly performing colonies and ensuring access to clean water are useful management measures. Any use of medicines should be based on local registration status, professional advice and strict observance of honey-harvest intervals.

Viral Diseases and Colony Decline

Several viruses may infect honey bees, including deformed wing virus, black queen cell virus, Kashmir bee virus, acute bee paralysis virus and sacbrood virus. Many viral infections remain unnoticed in healthy colonies because bees can tolerate low virus levels. However, when colonies are stressed by varroa mites, poor nutrition, pesticide exposure or queen failure, virus levels may increase and visible disease may occur. Deformed wing virus is particularly important because it is strongly linked with varroa infestation. Adult bees may emerge with shortened, twisted or crumpled wings. They are unable to fly or forage and usually die quickly. The appearance of deformed-wing bees is a warning that mite pressure may already be high.

There is no direct cure for most viral diseases. The best strategy is to control varroa mites, maintain strong colonies, provide adequate nutrition, avoid pesticide stress and rear queens from healthy, productive colonies. Colonies with repeated viral symptoms should be requeened and carefully assessed for mite levels and nutritional condition.

Integrated Pest and Disease Management

Integrated Pest and Disease Management, or IPDM, is a systematic approach that combines preventive and corrective practices. It reduces dependence on chemicals and protects honey quality, beeswax quality, bee health and environmental safety. The first principle of IPDM is proper apiary location. Apiaries should be established in dry, well-drained places with access to clean water and diverse floral resources. Hives should be protected from strong winds, flooding and excessive shade. At the same time, apiaries should be located away from intensive pesticide-use areas whenever possible. The second principle is colony strength. A strong queen-right colony can maintain brood temperature, defend the hive, remove diseased larvae, clean combs and suppress many pests naturally. Weak colonies should be requeened, reduced in size,

strengthened with appropriate management or united with other weak colonies. Keeping weak colonies for too long is often a major cause of pest multiplication. The third principle is comb management. Old brood combs accumulate cocoons, pathogen spores, pesticide residues and debris over time. Regular replacement of old combs reduces disease risk and improves brood health. Comb replacement should be gradual so that colony productivity is not severely affected. The fourth principle is hygiene and sanitation. Hive tools, gloves, smokers, extraction equipment, honey containers and storage rooms should be clean. The beekeeper should avoid moving contaminated tools directly from a suspected diseased colony to healthy colonies. Wax debris, dead bees, heavily infested combs and hive waste should be removed and disposed of safely. The fifth principle is monitoring and record keeping. Colony-wise records should include queen status, brood condition, mite levels, disease symptoms, treatments applied, feeding, honey harvest and colony losses. Such records help identify colonies that repeatedly suffer from disease or poor productivity. They also allow the beekeeper to evaluate whether a treatment or management practice was effective.

Pesticide Safety in Beekeeping

Pesticides used in agricultural crops can harm honey bees directly or indirectly. Bees may be exposed when insecticides are sprayed on flowering crops, weeds or nearby vegetation. They may also collect contaminated nectar, pollen or water. Acute pesticide poisoning may result in large numbers of dead or dying bees near hive entrances, trembling bees, abnormal movement and rapid loss of foragers. Beekeepers should communicate with nearby farmers, plantation managers and pesticide applicators. Farmers should be encouraged to avoid spraying insecticides during crop bloom and to spray after sunset when bees are less active. Selective and less bee-toxic pest-management methods should be preferred. Bee colonies may need to be moved or temporarily protected if hazardous pesticide application is unavoidable.

The beekeeper should provide clean water near the apiary to prevent bees from collecting contaminated water from irrigation channels, pesticide-mixing areas or drainage sites. Apiaries should not be placed immediately adjacent to crops receiving frequent insecticide applications. FAO recommends careful apiary-site selection and attention to pesticide use within the foraging area of colonies to reduce poisoning risk.

Seasonal Management of Bee Health

During the colony build-up period, the beekeeper should assess queen performance, food

stores, brood pattern and pest status. Weak queens should be replaced early. Old, damaged or diseased combs should be removed gradually. Colonies should be provided adequate space for expansion, but excessive empty space should be avoided. During the honey-flow season, the beekeeper should minimize disturbance and avoid unnecessary chemical treatments. Sufficient supers should be provided to prevent overcrowding and swarming. Honey should be harvested hygienically, and exposed honey or wet combs should not be left near the apiary because they may attract robbing bees, ants, wasps and hive beetles.

After honey harvest, colonies should receive careful inspection. This is often a suitable period to assess varroa levels, remove damaged combs, unite weak colonies and prepare colonies for the dearth period. The beekeeper should ensure that each colony has a productive queen, adequate adult-bee population and enough food reserves. During dearth, rainy or cold periods, colonies need protection from starvation, dampness, robbing and wax moth infestation. Hive entrances can be reduced where necessary, but ventilation must remain adequate. Colonies should not be opened unnecessarily during unfavourable weather. Emergency feeding may be required when food stores are low, and weak colonies should be consolidated rather than allowed to collapse.

Conclusion

Management of honey bee pests and diseases is not based on a single pesticide, medicine or control method. It is a continuous process of prevention, observation and timely action. The most productive colonies are generally those that are queen-right, well nourished, hygienic, properly housed and regularly inspected. Beekeepers should give priority to maintaining strong colonies, replacing failing queens, renewing old combs, preventing robbing, monitoring varroa mites, storing combs safely and avoiding unnecessary chemical use. In cases of suspected foulbrood, severe mite infestation or unexplained colony loss, laboratory diagnosis and expert support should be sought promptly. A healthy honey bee colony is not only a source of quality honey. It is also a vital biological asset that supports crop pollination, biodiversity, farm productivity and rural livelihood security. Sustainable bee health management therefore contributes directly to sustainable agriculture.

Volume: 06 Issue No: 10

AGROMETEOROLOGICAL INDICES FOR CROP YIELD PREDICTION

Article ID: AG-VO6-I10-11

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1. Introduction

Crop production is strongly influenced by seasonal and interannual variations in temperature, rainfall, solar radiation, evapotranspiration and soil moisture. Because weather conditions directly affect crop growth, development and yield formation, indices derived from meteorological variables can provide useful indicators for early crop-yield prediction. Agrometeorological indices integrate one or more weather parameters over specific crop-growth periods and thereby describe the environmental conditions experienced by a crop.

These indices are particularly useful in statistical and empirical yield-forecasting models because they require relatively simple inputs compared with detailed process-based crop models. They can also be combined with remote sensing, crop simulation and machine-learning approaches. Recent studies have demonstrated the usefulness of meteorological indices together with vegetation indices and satellite observations for crop-yield prediction [1–5]. Reliable yield forecasts can support farmers, agricultural planners, government agencies and policymakers in irrigation management, resource allocation, food-security planning and climate-risk assessment.

2. Theoretical Foundations of Agrometeorological Indices

Crop response to weather is generally nonlinear. Therefore, direct use of individual meteorological variables may not adequately explain crop-yield variability. Agrometeorological indices transform or combine weather variables according to crop requirements and growth stages. The major categories include **temperature-based, precipitation-based, radiation and evapotranspiration-based, and water-balance indices**.

2.1 Temperature-Based Indices

Temperature determines the rate of crop development and the duration of phenological stages. **Growing Degree Days (GDD)** are among the most widely used temperature-based indices:

$$GDD = \Sigma [(Tmax + Tmin)/2 - Tb]$$

where *Tmax* and *Tmin* are daily maximum and minimum temperatures and *Tb* is the crop-specific base temperature. Heat units, temperature anomalies, heat-stress indices, chilling units and vernalization indices are also used according to crop requirements.

GDD can successfully describe crop development when temperature remains within the suitable physiological range. However, it may overestimate yield under extreme heat because higher temperatures can accelerate maturity while reducing photosynthesis and grain-filling duration. Consequently, lower and upper temperature thresholds should be considered where appropriate. Temperature-based indices have been successfully applied to rice, wheat, maize, sorghum, pearl millet and other crops [1,2].

2.2 Precipitation-Based Indices

Rainfall is particularly important for rainfed agriculture. Total seasonal rainfall, rainfall during individual phenological stages, rainfall distribution and the number of rainy days can be used as yield predictors. The timing of rainfall is often more important than seasonal total rainfall because water requirements vary among vegetative, flowering and grain-filling stages.

Excess rainfall can cause waterlogging, nutrient loss and disease, whereas inadequate rainfall can cause drought stress. Therefore, precipitation indices are more effective when combined with evapotranspiration, soil moisture or water-balance information. Recent crop-yield studies have demonstrated that weather variables and derived indices can substantially improve statistical prediction models [2,6].

2.3 Radiation, Evapotranspiration and Light-Use Indices

Solar radiation provides the energy required for photosynthesis and biomass production. **Radiation Use Efficiency (RUE)** and **Light-Use Efficiency (LUE)** describe the efficiency with which crops convert absorbed solar radiation into biomass.

LUE may be expressed as the ratio of biomass production to absorbed photosynthetically active radiation. Radiation-based indices are particularly useful when combined with leaf area index (LAI), vegetation indices and satellite observations. Crop stress caused by drought, heat or nutrient deficiency generally reduces photosynthetic efficiency and consequently affects yield.

Evapotranspiration (ET) provides an integrated measure of atmospheric demand and crop water use. The relationship between actual and potential evapotranspiration can be used to identify water stress. Satellite-derived vegetation and meteorological indices have recently become important tools for regional and field-scale yield forecasting [3,5,8].

2.4 Water-Balance and Moisture-Stress Indices

Water balance represents the relationship between water supply and atmospheric demand. It incorporates rainfall, soil-water storage, crop evapotranspiration and drainage. Such indices are especially valuable for rainfed crops because drought occurring during sensitive stages such as flowering and grain filling can substantially reduce yield.

The **Moisture Stress Index (MSI)** and cumulative moisture-stress indicators can be used to quantify the severity and duration of water stress. Drought indices such as the Palmer Drought Severity Index and standardized precipitation/evapotranspiration-based indices provide additional information about seasonal moisture conditions. Pandya and Gontia [4] demonstrated the value of drought indices, remote sensing and machine learning for early crop-yield prediction and agricultural drought monitoring.

***3*. Data Sources and Methodological Considerations**

Reliable meteorological and crop data are essential for developing agrometeorological yield models. Important variables include maximum and minimum temperature, rainfall, relative humidity, sunshine duration, solar radiation, wind speed and evapotranspiration. Crop data should include historical yield, sowing and harvesting dates, crop duration and, where possible, information on irrigation, soil characteristics and management practices.

Weather observations may be obtained from agricultural meteorological observatories and national meteorological networks. Gridded and reanalysis datasets such as IMD products, ERA5 and other global climate datasets can provide spatially continuous information. Satellite observations provide additional information through NDVI, vegetation-health indices, LAI and other biophysical variables.

The spatial and temporal resolution of the data should be appropriate for the crop and study region. Daily data are preferred for process-based modelling, whereas monthly, seasonal or phenological-stage data may be sufficient for statistical approaches. Missing observations should be detected and carefully imputed, while extreme values require quality control.

For reliable statistical models, sufficiently long historical datasets are desirable. Data from at least 20–30 years are generally useful for identifying stable relationships, although the required period depends on crop, location and data quality.

4. Major Agrometeorological Indices and Yield Prediction

4.1 Growing Degree Days and Heat Units

GDD and heat units quantify accumulated thermal energy during crop development. Their relationship with yield varies according to crop and temperature regime. Yadav and Shukla [2] demonstrated the potential of weather-variable-based statistical approaches for maize-yield prediction. Bottu et al. [1] also highlighted the usefulness of agrometeorological indices in assessing rice phenology and growth.

Although GDD is simple and widely applicable, it should not be considered a universal yield predictor. Heat stress, temperature extremes and cultivar differences can modify the relationship between accumulated temperature and final yield.

4.2 Chilling and Vernalization Indices

Chilling and vernalization indices are important for winter cereals, fruit crops and other plants requiring exposure to low temperatures for normal development. Insufficient chilling can delay flowering and reduce yield. These indices are particularly relevant under climate change because warmer winter temperatures may alter crop phenology and suitability.

4.3 Moisture-Stress and Drought Indices

Moisture stress is one of the major causes of yield variability in rainfed agriculture. MSI, cumulative moisture stress, drought indices and water-balance indicators can identify periods when crop water requirements are not adequately met. The effect of stress should preferably be calculated separately for different growth stages because flowering and grain filling are often highly sensitive to water deficits.

4.4 Rainfed and Irrigated Conditions

The importance of individual indices differs between rainfed and irrigated crops. Rainfed crops are generally more sensitive to rainfall distribution, soil moisture and drought indices, whereas irrigated crops may show stronger relationships with temperature and radiation. Nevertheless, excessive rainfall can affect even irrigated crops through waterlogging, disease and harvesting difficulties.

4.5 Radiation and Light-Use Efficiency

RUE and LUE are increasingly integrated with satellite observations. Zhu et al. [7] demonstrated the potential of combining agrometeorological indices with remote sensing data for crop-yield prediction. Remote sensing allows the spatial monitoring of crop development and stress, while meteorological indices provide information on the environmental drivers responsible for yield variability.

5. Modelling Approaches

Agrometeorological indices can be incorporated into **statistical, process-based, hybrid and machine-learning models**.

5.1 Statistical Models

Statistical approaches establish empirical relationships between crop yield and weather indices using correlation, regression, principal component analysis and other multivariate techniques. Multiple linear regression can combine several indices, such as temperature, rainfall and radiation, to improve prediction. Principal component analysis can reduce multicollinearity among weather variables [2].

Statistical models are relatively simple and require less computational effort, but their performance may decline when applied outside the climatic conditions represented in the training dataset.

5.2 Process-Based Models

Process-based crop models simulate physiological processes such as phenological development, photosynthesis, biomass accumulation and water stress. They require detailed weather, soil and crop-management information. Their major advantage is the ability to simulate crop response under different weather and climate scenarios. However, extensive calibration and high-quality input data are required.

5.3 Hybrid and Machine-Learning Models

Combining agrometeorological indices with remote sensing and machine learning can improve prediction accuracy. Artificial Neural Networks, Random Forest, XGBoost and deep-learning methods can represent complex nonlinear relationships between yield and environmental variables. Gupta et al. [11] demonstrated the potential of artificial neural networks for weather-based crop-yield prediction, while Kheir et al. [10] reported benefits from combining remote sensing, soil and weather datasets.

Recent research has further expanded machine-learning applications for potato, wheat and other crops [8,9,13]. Xu et al. [3] showed the value of combining multiscale vegetation and meteorological indices for winter-wheat yield prediction. Such approaches provide opportunities for near-real-time, spatially explicit crop monitoring.

6. Validation, Uncertainty and Model Evaluation

Yield-prediction models must be independently validated before operational application. Common evaluation measures include **Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Square Error (RMSE), Relative RMSE (RRMSE), coefficient of determination (R^2), Nash–Sutcliffe Efficiency (NSE)** and index of agreement.

Uncertainty can originate from weather observations, missing data, crop parameters, model structure and yield observations. Sensitivity analysis helps identify the variables that contribute most to prediction uncertainty. Techniques such as Monte Carlo simulation, Latin Hypercube sampling and Sobol sensitivity analysis can be used to quantify uncertainty.

Models should preferably be tested using independent years or locations rather than only the data used for calibration. This reduces overfitting and provides a more realistic assessment of predictive performance.

7. Applications in Agricultural Planning and Climate Adaptation

Agrometeorological indices have considerable potential for operational agricultural decision-making. Seasonal yield forecasts can help farmers select suitable crops and sowing dates, plan irrigation and identify drought risks. Government agencies can use yield forecasts for food-security planning, procurement and disaster preparedness. Insurance agencies may also use reliable forecasts for agricultural-risk assessment.

Water-balance and moisture-stress indices can support irrigation scheduling by identifying periods of increasing crop-water stress. Remote sensing combined with meteorological indicators can identify spatially vulnerable areas and facilitate targeted interventions.

Under climate change, agrometeorological indices can help identify shifts in crop suitability, changes in growing-season duration and increasing risks from heat and drought. However, indices should be calibrated for individual crops and regions because crop sensitivity to temperature, rainfall and moisture varies considerably.

Conclusion

Agrometeorological indices provide a practical and scientifically useful approach for understanding and predicting crop-yield variability. Temperature-based indices such as GDD, rainfall and moisture indices, water-balance indicators, drought indices and radiation-use efficiency can effectively describe the major environmental controls of crop production. Their integration with remote sensing, statistical modelling, process-based simulation and machine learning has considerably expanded their application in regional and near-real-time crop-yield forecasting.

The reliability of these models depends on the quality and temporal-spatial resolution of weather and crop data, appropriate index selection, crop-specific calibration and independent validation. Future yield-forecasting systems should increasingly integrate ground observations, satellite data, agrometeorological indices and advanced machine-learning techniques. Such integrated systems can contribute significantly to climate-resilient agriculture, efficient water management, food-security planning and sustainable agricultural development.

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Volume: 06 Issue No: 10

CLIMATE CHANGE AND ITS IMPACT ON INDIAN AGRICULTURE

Article ID: AG-VO6-I10-12

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1. Introduction

Climate change is one of the major challenges confronting agricultural production and food security. Agriculture is highly dependent on climatic conditions, and changes in temperature, rainfall, atmospheric carbon dioxide (CO_2), and the frequency of extreme weather events can substantially influence crop growth and productivity. India is particularly vulnerable because a large proportion of its agricultural area is rainfed and millions of rural households depend directly or indirectly on agriculture.

Observed warming, increasing rainfall variability, droughts, floods, heat waves and cyclones are already affecting Indian agriculture. The magnitude of these effects varies considerably among regions and crops. Climate change may shorten crop growth duration, increase water requirements, alter pest and disease incidence, and reduce yields when temperature and moisture conditions exceed crop-specific thresholds (Aggarwal, 2008; Mishra, 2020).

2. Major Mechanisms Affecting Agriculture

Climate change influences Indian agriculture through four major pathways: **temperature and heat stress, altered rainfall and drought, extreme weather events, and elevated atmospheric CO_2.**

2.1 Temperature and Heat Stress

Rising temperatures and more frequent heat waves are particularly damaging during flowering and grain-filling stages. Wheat is highly sensitive to terminal heat stress, while rice productivity also declines when temperatures exceed critical thresholds. Higher temperatures can

shorten crop duration, accelerate phenological development, increase evapotranspiration and intensify pest and disease pressure. Climate projections indicate increasing heat-wave frequency and intensity, particularly in northwestern and central India.

2.2 Rainfall Variability and Drought

The Indian monsoon is characterized by substantial spatial and temporal variability. Changes in the onset, duration and distribution of rainfall can increase the frequency of dry spells and droughts in vulnerable regions. Rainfed crops such as pulses, millets, soybean and groundnut are particularly exposed to rainfall uncertainty. At the same time, excessive rainfall over short periods can cause flooding, soil erosion, nutrient losses and waterlogging.

2.3 Extreme Weather Events

Floods, cyclones, intense rainfall, landslides and droughts directly damage crops and agricultural infrastructure. Waterlogging reduces soil aeration and promotes soil-borne diseases, while cyclones may cause crop lodging, salinity intrusion and damage to horticultural plantations. Coastal agricultural regions of Gujarat, Maharashtra and eastern and southern India are particularly vulnerable to combinations of flooding and salinity.

2.4 CO_2 Fertilization

Increasing atmospheric CO_2 can stimulate photosynthesis and biomass production, particularly in C_3 crops such as rice and wheat. However, the beneficial CO_2 fertilization effect may not compensate for losses caused by high temperature, water stress, nutrient limitations and extreme weather. Therefore, crop responses to climate change depend on interactions among CO_2, temperature, water and nutrient availability.

3. Regional Impacts

The impact of climate change varies substantially across India. **North India**, including the Indo-Gangetic Plains, faces increasing heat stress on wheat and rice. Terminal heat can reduce wheat grain filling and yield, making timely sowing and heat-tolerant varieties important adaptation measures.

Western India, including Gujarat and Maharashtra, is characterized by increasing temperature, rainfall variability and drought risk. Cotton, groundnut, soybean, sugarcane and horticultural crops are vulnerable to both moisture stress and extreme rainfall. Efficient irrigation, rainwater harvesting, watershed development and groundwater recharge are therefore essential.

Central India is increasingly exposed to heat and rainfall variability affecting soybean, chickpea, wheat and other rainfed crops. Development of heat- and drought-tolerant varieties, improved soil moisture conservation and crop diversification can reduce vulnerability.

In **South India**, droughts, floods and changing rainfall patterns affect rice, sugarcane and horticultural crops. Efficient irrigation scheduling and water-use efficiency are particularly important. The **Northeastern region**, despite receiving substantial rainfall, faces increasing risks from erratic rainfall, flash floods and landslides. Crop diversification, community seed systems, rainwater harvesting and timely weather information can strengthen resilience.

4. Impacts on Major Crops

Rice

Rice production is sensitive to temperature, rainfall and water availability. High temperatures during flowering and grain filling can significantly reduce yield. Although elevated CO_2 may stimulate rice growth, this benefit can be offset by heat stress, drought and flooding. Improved irrigation, heat-tolerant varieties, appropriate sowing dates and efficient nutrient management are important adaptation strategies.

Wheat

Wheat is among the crops most vulnerable to climate warming in India, particularly in the Indo-Gangetic Plains. High temperatures during the reproductive stage reduce grain-filling duration, grain weight and final yield. Adaptation includes timely or early sowing, heat-tolerant and short-duration varieties, improved irrigation, laser land levelling, balanced fertilization and improved soil management. Climate variability and temperature anomalies during January–April are particularly important for wheat productivity.

Millets and Pulses

Millets generally possess greater drought tolerance than many cereals and therefore have considerable potential under climate variability. However, prolonged moisture stress and high temperature can still reduce productivity. Pulses are important for food security and soil fertility through biological nitrogen fixation, but they are sensitive to heat and moisture stress. Diversification toward drought-tolerant millets and pulses can reduce production risk in rainfed agriculture.

Sugarcane and Horticultural Crops

Sugarcane requires substantial water and is vulnerable to drought during tillering and grand growth stages. Changes in temperature, rainfall and humidity can also affect sucrose accumulation. Improved irrigation scheduling and water-use efficiency are therefore essential. Horticultural crops are highly sensitive to changes in temperature, rainfall, humidity and extreme events. Mango, banana, citrus, grape, potato, onion, coffee, cardamom and black pepper may experience changes in flowering, fruit set, quality and disease incidence. Climate-based crop zoning and protected cultivation can help reduce these risks.

5. Water Resources and Irrigation

Climate change is expected to influence river discharge, groundwater recharge and irrigation-water availability. Groundwater has traditionally acted as a buffer against rainfall variability, but over-extraction has resulted in declining water tables and increasing pumping costs in several regions. Sustainable groundwater management is therefore critical for agricultural resilience (Zaveri et al., 2016).

Efficient irrigation scheduling should consider crop water requirements, soil moisture, rainfall forecasts, crop growth stage and available water resources. Drip and sprinkler irrigation, mulching, deficit irrigation where scientifically appropriate, and improved water-use efficiency can reduce water consumption without proportionally reducing yield.

Rainwater harvesting through farm ponds, check dams, contour bunding, percolation tanks and watershed development can increase water availability and groundwater recharge. Integration of rainwater harvesting with soil moisture conservation and improved crop varieties can substantially reduce drought risk.

6. **Climate-Smart Agriculture and Adaptation**

Climate-smart agriculture aims to increase productivity and income, strengthen resilience and, where possible, reduce greenhouse gas emissions. Important practices for India include:

- adoption of heat-, drought- and flood-tolerant crop varieties;
- adjustment of sowing and harvesting dates;
- crop diversification toward millets, pulses and oilseeds;
- drip and sprinkler irrigation and improved irrigation scheduling;
- rainwater harvesting and groundwater recharge;
- integrated nutrient management and improvement of soil organic matter;

- conservation agriculture and residue management;
- integrated pest and disease management;
- agroforestry and restoration of degraded lands;
- weather-based advisories and climate information services; and
- crop insurance and other financial risk-management mechanisms.

Healthy soils improve water and nutrient availability and increase crop resilience to climatic stresses. Integrated nutrient management, organic matter addition and balanced fertilizer use are therefore important components of climate adaptation (Aryal et al., 2018).

Conclusion

Climate change presents a serious and increasingly complex challenge to Indian agriculture. Rising temperatures, changing rainfall patterns, droughts, floods and other extreme events can reduce crop productivity and threaten food and livelihood security. The effects vary considerably among regions and crops, making location-specific adaptation essential. Strengthening climate-resilient varieties, efficient irrigation, rainwater harvesting, soil-health management, crop diversification, weather forecasting, crop insurance and climate-smart agricultural practices can substantially reduce vulnerability. Future agricultural policies should integrate climate projections with local agro-ecological conditions and farmer knowledge to ensure sustainable productivity, water security and food security in India.

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Volume: 06 Issue No: 10

EFFICIENT WATER MANAGEMENT THROUGH DRIP IRRIGATION FOR HIGHER CROP PRODUCTIVITY

Article ID: AG-VO6-I10-13

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Introduction

With water resources becoming increasingly scarce, efficient utilization of available water has become an urgent necessity. In this context, Drip Irrigation is an efficient modern irrigation technology that improves water-use efficiency by delivering the required quantity of water directly to the root zone of crops. In addition to saving water, drip irrigation improves fertilizer-use efficiency and can contribute to higher crop productivity.

What is Drip Irrigation?

Drip irrigation is a method in which water is delivered slowly and continuously to the root zone of individual plants through a network of pipes and drippers (emitters). Since water is applied directly to the root zone, unnecessary water loss through runoff and evaporation is minimized. Drip irrigation is particularly suitable for fruit crops, coconut, sugarcane, cotton, maize, vegetable crops, flower crops and long-duration horticultural crops.

Major Features of Drip Irrigation

- Supplies only the required quantity of water to the crop.
- Delivers water directly to the root zone, reducing evaporation and runoff losses.
- Enables application of water-soluble fertilizers through fertigation.
- Can be used in different types of soils.
- Performs well in sloping lands and sandy soils.
- Provides uniform and controlled water application.
- Helps maintain optimum soil moisture around the crop root zone.

Water Saving

Unlike conventional surface irrigation methods, drip irrigation wets only the portion of

soil where the crop roots are actively growing. Generally, only about 30–40% of the field area may remain wetted, depending on crop, soil type and emitter spacing. By minimizing evaporation, runoff and deep percolation losses, drip irrigation can provide substantial savings in irrigation water, potentially up to 50–60% compared with conventional irrigation under suitable conditions.






Improved Fertilizer-Use Efficiency

Drip irrigation enables fertigation, in which water-soluble fertilizers are mixed with irrigation water and delivered directly to the crop root zone using a Venturi injector or fertilizer injection unit.

Advantages of Fertigation

- Improves fertilizer-use efficiency.
- Reduces fertilizer wastage and nutrient losses.
- Supplies nutrients to the crop at the appropriate growth stages.
- Maintains a more uniform supply of nutrients in the root zone.
- Reduces fertilizer application and labour requirements.
- Supports improved crop growth and productivity.

Under suitable crop and management conditions, fertilizer use and associated costs can be reduced by up to about 25%.

Weed Management

Since drip irrigation wets only the crop root zone, the areas between crop rows remain relatively dry. This can suppress weed emergence compared with methods that wet the entire field.

Benefits

- Reduces weed growth.
- Reduces the cost of manual weeding.
- Reduces labour requirement.
- Improves the efficiency of weed management operations.

Major Benefits of Drip Irrigation

- Up to 50–60% water saving under suitable conditions.
- Up to 25% reduction in fertilizer cost through efficient fertigation.
- Up to 25–30% reduction in labour requirement in appropriate cropping systems.
- Better control over the timing and quantity of irrigation.
- Improved fertilizer-use efficiency.
- Reduced waterlogging and unnecessary wetting of the field.
- Better crop growth and potential improvement in yield and quality.
- Particularly useful for water-scarce and drought-prone areas.

Important Points for Successful Drip Irrigation

For obtaining maximum benefits, the drip irrigation system should be designed according to the crop, soil type, plant spacing, water quality, field topography and available water source. Proper filtration, periodic flushing of laterals, checking of drippers for clogging and regular maintenance of the system are essential. Irrigation should be scheduled according to crop growth stage, soil moisture and prevailing weather conditions rather than applying a fixed quantity of water throughout the crop period.

Conclusion

With increasing water scarcity, every drop of water must be used efficiently. Drip irrigation is an important water-saving technology that enables precise application of water and nutrients to the crop root zone. By reducing water wastage and improving fertilizer-use

efficiency, it can help reduce production costs and enhance crop productivity. Therefore, farmers are encouraged to adopt properly designed and maintained drip irrigation systems according to their crop and field conditions. Efficient irrigation management can contribute to water conservation, sustainable agricultural production, higher productivity and improved farm income.

Volume: 06 Issue No: 10

FISHERIES CO-MANAGEMENT AS A TOOL FOR ADDRESSING SOCIOLOGICAL ISSUES: PARTICIPATION, EQUITY, CONFLICT RESOLUTION AND LIVELIHOOD SECURITY

Article ID: AG-VO6-I10-14

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Abstract

Fisheries are not only ecological systems but also complex social systems involving fishers, fishing communities, traders, processors, boat owners, government agencies, researchers and other stakeholders. Consequently, fisheries problems such as resource competition, conflicts, poverty, inequality, gender disparities and poor compliance with regulations cannot be addressed through biological management alone. Fisheries co-management provides an alternative governance approach in which responsibility and authority are shared between government and resource users. It promotes participation, decentralization, local knowledge, social justice, livelihood security and collective responsibility.

1. Introduction

Traditional fisheries management has largely followed a centralized, top-down approach in which governments formulate regulations related to fishing effort, fishing seasons, gears, protected areas and access to resources. Although government regulation is essential, it may not adequately reflect the experiences, knowledge and socioeconomic conditions of fishing communities. Fishers possess valuable knowledge regarding fishing grounds, seasonal changes, fish abundance and local environmental conditions. Excluding this knowledge from management decisions may reduce the acceptance and compliance of regulations. Fisheries are also characterized by competition among different resource users. Conflicts may occur between mechanized and traditional fishers, trawlers and small-scale fishers, different gear groups, and communities competing for fishing grounds and resources. These problems have important sociological dimensions. Co-management provides a framework in which governments and

resource users share responsibility and authority for fisheries management. It is considered a dynamic partnership that combines the administrative and legal capacity of government with the knowledge, interests and capabilities of fishing communities. Co-management therefore shifts fisheries governance from a purely regulatory approach towards collaboration and shared responsibility.

2. Major Sociological Issues in Fisheries

2.1 Conflict among resource users

Conflict is one of the most common sociological problems in fisheries. Competition over fishing grounds, access rights, fishing seasons and fishing gears can create disputes among different fishing groups. Such conflicts may reduce social cohesion and make fisheries regulations difficult to implement. Along the Coromandel coast, fishing communities developed customary regulations to restrict destructive fishing practices. These arrangements reflected both ecological concerns and principles of social justice (Bavinck, 1996). Co-management can provide a platform where competing groups jointly identify problems, negotiate acceptable rules and participate in conflict resolution.

2.2 Lack of participation and representation

A major weakness of conventional fisheries governance is the limited involvement of resource users in decision-making. Fishers may be expected to follow regulations in whose development they had little involvement. This can reduce legitimacy and encourage non-compliance. Co-management promotes participation by involving fishers and other stakeholders in planning, implementation and monitoring. Participation should, however, be meaningful rather than merely consultative. Resource users should have genuine opportunities to influence decisions.

2.3 Inequality, equity and social justice

Fishing communities are not homogeneous. Differences may exist in wealth, gender, occupation, fishing gear, boat ownership, social status and access to markets. Powerful groups may dominate community institutions, potentially reproducing existing inequalities. Co-management should therefore promote equitable representation and access to resources and decision-making. Women, small-scale fishers, youth and economically weaker groups should have opportunities to participate in fisheries institutions. Equity and social justice are important outcomes of effective co-management.

3. Co-management as a Response to Sociological Problems

3.1 Power sharing and decentralization

The major contribution of co-management is the sharing of management authority. Government continues to provide legal, scientific, monitoring and enforcement support, while fishing communities contribute local knowledge, experience and social institutions. Such decentralization can create a stronger sense of ownership among fishers and encourage voluntary compliance. However, communities must receive sufficient authority and resources; simply transferring responsibilities without decision-making power does not constitute genuine co-management.

3.2 Building trust

Lack of trust between fishers and government agencies can be a major barrier to effective fisheries management. Fishers may perceive government officials as imposing regulations without understanding local conditions, while authorities may view fishers mainly as rule violators. Co-management can gradually change this relationship from "regulator versus regulated" to "partners in resource management." Jentoft et al. (1998) emphasized that social relationships, legitimacy and institutional trust are central to fisheries co-management. Co-management is therefore both an administrative and a social process.

3.3 Local and traditional knowledge

Fishing communities possess valuable knowledge accumulated over generations. Fishers can identify seasonal fishing grounds, spawning areas, migration patterns and changes in fish abundance that may not be captured through short-term scientific surveys. Co-management provides an opportunity to integrate local knowledge with scientific information. Such integration can improve management decisions and increase the confidence of communities in fisheries regulations. FAO recognizes the importance of incorporating traditional knowledge and fisher participation into fisheries management.

4. Gender and Social Inclusion

Women play important roles in fisheries through fish processing, marketing, trading, drying, transportation and household financial management. However, their contribution is frequently under-represented in fisheries decision-making. FAO emphasizes the importance of women's participation and identifies continuing inequalities in access to resources, services,

employment and decision-making. Co-management institutions should therefore include women and other marginalized groups in decision-making.

5. Co-management and Livelihood Security

Co-management can link conservation with livelihood security by allowing communities to participate in developing management measures. Seasonal closures, for example, can be combined with alternative employment, skill development, value addition, improved marketing and livelihood-support programmes. Cooperative organizations can also improve collective bargaining, marketing and access to services. Studies from Indian fisheries indicate that local fishing organizations and cooperative institutions can contribute to collective resource management when appropriate institutional conditions exist (Tyagi et al., 2015).

6. Types of Fisheries Co-management

Sen and Nielsen (1996) identified five broad forms of fisheries co-management based on the relative roles of government and resource users:

1. **Instructive:** Government makes decisions and mainly informs fishers.
2. **Consultative:** Government consults fishers, but retains final decision-making authority.
3. **Cooperative:** Government and fishers participate as relatively equal partners in decision-making.
4. **Advisory:** Fishers provide advice and government considers or endorses their recommendations.
5. **Informative/Delegated:** Authority is delegated to fisher organizations, which make decisions and inform government.

7. Co-management Experiences in India

India has a long history of community participation and customary fisheries management. Fishing communities have traditionally developed rules concerning fishing grounds, fishing gears, seasons and access rights. Along the Coromandel coast, customary regulations developed by fishing communities have addressed destructive fishing practices and reflected collective interests and social justice (Bavinck, 1996). The Cherai Poyil fishery in Kerala provides an example of movement from state control towards community-based and co-management arrangements. Such experiences demonstrate that local institutions can contribute to fisheries governance when they are appropriately recognized and supported.

8. Challenges and Limitations

Co-management is not automatically successful. Major challenges include:

- domination of institutions by powerful groups;
- elite capture of benefits and decision-making;
- inadequate representation of women and marginalized groups;
- insufficient technical and financial capacity;
- conflicts among stakeholders;
- lack of trust between communities and government; and
- token participation without genuine power sharing.

Conclusion

Fisheries co-management is an important approach for addressing the sociological dimensions of fisheries governance. It recognizes that sustainable fisheries depend not only on biological conservation but also on participation, equity, trust, social justice and livelihood security. By sharing authority between government and fishing communities, co-management can improve acceptance of regulations, strengthen local institutions, reduce conflicts and incorporate traditional knowledge. It can also provide greater opportunities for women and marginalized groups to participate in fisheries governance. Thus, the future of sustainable fisheries management depends on moving from centralized control towards collaborative governance, where fishers, government, scientists and other stakeholders share responsibility for conserving resources and securing the livelihoods of fishing communities.

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Volume: 06 Issue No: 10

UNDERSTANDING POKKAH BOENG IN SUGARCANE: PATHOGEN DYNAMICS, MICRONUTRIENT INTERACTIONS AND FIELD MITIGATION

Article ID: AG-VO6-I10-15

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Introduction

Pokkah Boeng remains a highly disruptive threat to global sugarcane production. Derived from a Javanese term describing a "malformed or distorted top," this disease strikes during periods of rapid vegetative growth. While traditionally managed strictly as a fungal disease, modern agronomy recognises that its severity is deeply intertwined with plant nutrition—specifically micronutrient deficiencies.

When sugarcane lacks critical trace elements, its anatomical barriers and biochemical defense systems break down, opening the door for devastating infections. This article provides a comprehensive overview of the disease, its complex relationship with micronutrient imbalances, diagnostic differentiation, and integrated field management.

1. The Pathogen and Disease Cycle

Pokkah Boeng is caused primarily by the ***Fusarium* species complex**, historically classified as *Fusarium moniliforme* (sexual stage: *Gibberella fujikuroi*).

Transmission Pathways

- **Primary Spread**: The fungus survives in soil debris and infected stubble. As temperatures rise and humidity peaks during the summer and monsoon seasons, the fungus releases microscopic spores (microconidia and macroconidia). These spores are easily lifted and carried over long distances by **wind currents**.

- **Secondary Spread**: Within a field, the disease spreads via splashing rainwater, contaminated irrigation channels, and unsterilised harvesting tools.
- **The Role of Pests**: Sucking and boring insects, such as the top borer (*Scirpophaga excerptalis*) or crown mealybugs, create physical puncture wounds. These entry points allow fungal spores to bypass the plant's outer defenses and directly invade internal tissues.

2. Progressive Disease Symptoms

The disease manifests in three distinct, chronological phases based on severity:

[Chlorotic Phase] ⟶ [Top Rot Phase] ⟶ [Knife Cut Phase]

(Leaf yellowing/wrinkling) (Spindle rot & death) (Deep structural lesions)

1. **The Chlorotic Phase**: The earliest sign is a distinct loss of green pigment (chlorosis) at the base of young, unfolding leaves. These leaves become narrow, wrinkled, twisted, and fail to unfold properly, creating a "hooked" or tangled top appearance.
2. **The Top Rot Phase**: If environmental conditions remain warm and waterlogged, the fungus penetrates deep into the growing point (the spindle). The tissue turns brown or black, rots completely, and emits a foul odour. The main shoot dies, halting vertical growth.
3. **The Knife Cut Phase**: In advanced cases, the fungal toxins disrupt cell division in the developing stalk. This creates sharp, transverse, parallel cuts across the internodes, looking exactly as if a chunk of tissue was sliced away cleanly with a sharp knife.

3. The Critical Link: Micronutrient Deficiencies

A sugarcane crop's nutritional status dictates its vulnerability to Pokkah Boeng. Micronutrients are not merely plant food; they are structural building blocks and biochemical catalysts. When these are deficient, the plant’s natural resistance mechanisms collapse.

Boron (B) and Calcium (Ca) Structural Failure

Boron is fundamental for cell wall synthesis and the structural stability of the middle lamella. Calcium acts as the cellular "glue."

- **The Link**: A shortage of Boron causes cell walls in the rapidly growing spindle to become weak, fragile, and brittle. The fungal hyphae of *Fusarium* can easily pierce these compromised cell walls, accelerating the transition from the mild chlorotic phase to the fatal top rot phase.

Zinc (Zn) and Manganese (Mn) Biochemical Defense Shutdown

Plants defend themselves against fungal pathogens by producing phytoalexins, lignin, and phenolic compounds that "wall off" the infection. These pathways are driven by specific enzymes that require Zinc and Manganese to function.

- **The Link**: When Zinc or Manganese is low, the sugarcane plant cannot execute its internal chemical defense strategy fast enough. The fungus spreads unchecked through the vascular bundles (xylem and phloem).

The Secondary Nutrient Drain

Research indicates that the relationship is a two-way street. Once *Fusarium* establishes itself inside the sugarcane stalk, it actively disrupts the plant's vascular translocation. Chemical analyses of infected tissues consistently show **drastically lower concentrations of Zinc, Iron, and Copper** compared to healthy, uninfected canes of the same age. The disease itself induces a localized micronutrient famine, trapping the plant in a degenerative cycle.

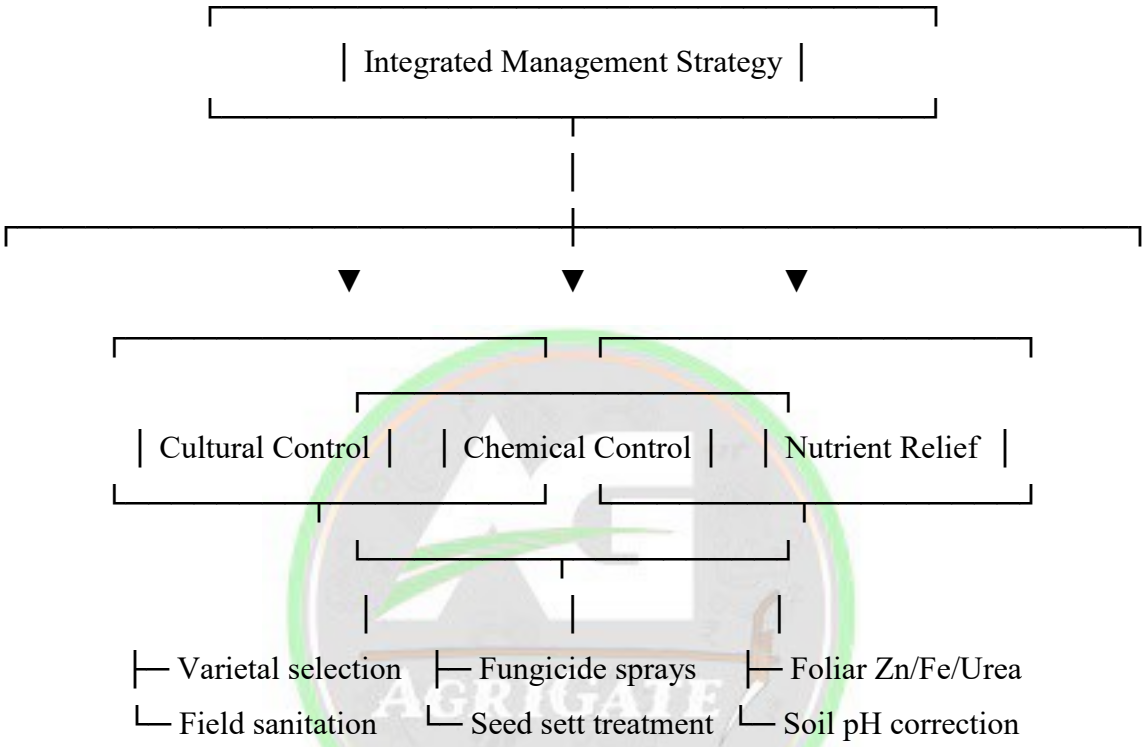
4. Diagnostics: Fungal Infection vs. Nutrient Deficiency

Because both Pokkah Boeng and basic trace mineral deficiencies cause young leaves to turn yellow or white, visual misdiagnosis is common. Mistaking a fungal attack for a simple nutrient deficiency—or vice-versa—leads to wasted inputs and crop loss.

Diagnostic Marker	Pure Micronutrient Deficiency	Pokkah Boeng (Fungal Pathogen)
Symptom Pattern	Uniform across the field or along specific soil patches; follows a regular green/yellow striping pattern on leaves.	Scattered, random distribution across individual plants; localized strictly at the lower leaf base.
Leaf Morphology	Leaves remain straight and structurally flat, despite losing colour.	Leaves become **severely distorted, wrinkled, telescoped**, or tied into knots.
Internal Vascular Tissue	Clean, white, or light green when sliced open.	Red, brown, or black vascular discoloration extending down into the stalk nodes.
Structural Integrity	Stalk tissues remain solid and intact.	Presence of **Knife Cut** lesions and structural cavities in the internodes.

5. Integrated Disease and Nutritional Management Strategy

Relying solely on chemical fungicides will not yield sustainable control if the underlying soil is chemically depleted. True remediation requires a dual approach that eliminates the pathogen while rapidly rebuilding plant immunity.



Step 1: Preventative Cultural Practices

- **Resistant Varieties**: Avoid planting highly susceptible cultivars in regions prone to high humidity and waterlogging.
- **Sanitation**: Manually rogue out and burn plants showing severe top rot or knife-cut symptoms during early crop growth to prevent windborne spores from blanketing the field.
- **Aeration**: Ensure proper row spacing and timely field detrashing (removing old, dead lower leaves) to maximize sunlight penetration and lower the microclimate humidity around the canes.

Step 2: Therapeutic Nutritional & Fungicidal Foliar Sprays

When early symptoms appear, apply a tank-mix combination that delivers a therapeutic knock-out dose to the fungus while feeding the leaf tissue directly.

Apply a foliar spray containing the following per litre of water, repeating 15 days later if necessary:

- **Systemic Fungicide**: Carbendazim 50% WP (1.0 gram) OR Thiophanate-methyl 70% WP (1.0 gram) to stop fungal replication.
- **Nutritional Boosters**: Zinc Sulfate ($ZnSO_4$) at 1.0 gram and Ferrous Sulfate ($FeSO_4$) at 1.0 gram to kickstart enzyme production and chlorophyll synthesis.
- **Surfactant/Urea**: Add a small amount of Urea (5 grams/litre) to the mix; it acts as a penetrant, opening up leaf stomata for rapid mineral absorption.

Step 3: Soil Amelioration and Sett Treatment

- **Pre-Planting Treatment**: Always soak seed setts in a solution of Propiconazole 25% EC (2 ml per litre of water) for 15-20 minutes before planting to eliminate seed-borne inoculum.
- **Soil Application**: Based on a comprehensive soil test, apply a balanced micronutrient mixture containing Zinc, Manganese, and Boron at a rate of 25 kg per hectare, blended thoroughly with enriched compost or farmyard manure during the first earthing-up operation.
- **pH Correction**: Maintain soil pH between 6.5 and 7.5. Acidic or overly alkaline soils chemically lock up micronutrients, making them unavailable to the roots regardless of how much fertilizer is applied.

By addressing both the biological pathogen and the environmental stress factors simultaneously, sugarcane growers can effectively insulate their crops against Pokkah Boeng, ensuring structural cane integrity and high sucrose yields.

Volume: 06 Issue No: 10

ZEOLITE: A POTENTIAL SOURCE OF SOIL AMENDMENTS TO IMPROVE SOIL PROPERTIES

Article ID: AG-VO6-I10-16

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Abstract

Zeolites are porous, crystalline aluminosilicate minerals with a rigid, cage-like framework that carries a permanent negative charge. This structure lets them hold water and exchange cations such as ammonium, potassium and calcium without losing their shape. Mined from volcanic deposits or produced synthetically, zeolites are now being tested as soil amendments in light-textured, acidic, saline and nutrient-poor soils. This article describes what zeolites are, how their structure gives rise to useful soil properties, and how they influence cation exchange, water retention, nutrient use efficiency, soil reaction and the fate of contaminants. It also considers the major practical limits, including cost, application rate, sodium saturation and quality variation between deposits, and highlights where field research is still needed.

Keywords: zeolite, soil amendment, cation exchange capacity, nutrient retention, water holding capacity

Introduction

Soil is asked to do more each year. It must feed a growing population, hold on to costly fertilisers, store rainfall and stay productive under repeated cropping. Many soils struggle with these demands. Sandy soils drain too quickly and lose nutrients below the root zone, while eroded and highly weathered soils carry little organic matter and few exchange sites. In such conditions a large share of applied nitrogen and potassium never reaches the crop, which raises costs for farmers and adds to water pollution.

Organic manures, lime, gypsum and clay-based materials have long been used to correct these problems. In recent decades attention has also turned to mineral amendments that work through their own structure and are stable for many years. Zeolites belong to this group. They have been used for water softening, gas separation and animal feed, and the same traits that make them useful there, namely a high surface area, uniform pores and a strong appetite for certain cations, are valuable in soil as well (Mumpton, 1999).

This article gives a short account of zeolites as a soil amendment. It begins with their structure and origin, then describes the main ways they change soil physical, chemical and biological behaviour, and ends with practical limits and research gaps.

What is a zeolite?

The name comes from Greek words meaning “boiling stone”, since the mineral releases steam when heated. Chemically, zeolites are hydrated aluminosilicates of alkali and alkaline-earth metals. Their framework is built from SiO_4 and AlO_4 tetrahedra joined at the corners through shared oxygen atoms. Wherever aluminium (3+) replaces silicon (4+) in a tetrahedron, the framework gains one unit of negative charge. That charge is balanced by loosely held cations such as sodium, potassium, calcium and magnesium, which sit inside the channels together with water molecules (Breck, 1974).

Because these balancing cations are not bonded into the framework, they can be swapped for other cations in the surrounding solution. The channels are also of fixed, molecular dimensions, so a zeolite can admit some ions and molecules while excluding others. Over forty natural species are known, but clinoptilolite is by far the most common in agricultural use because it occurs in large sedimentary deposits and has a marked preference for ammonium and potassium. Synthetic zeolites can be tailored for particular tasks, although their higher price limits use in the field.

Origin and availability

Natural zeolites form when volcanic glass reacts with water, usually in alkaline lakes, in marine basins or through percolating groundwater. The resulting beds can be thick and widespread, and some are mined in countries such as the United States, Cuba, Turkey, China, Japan, Hungary and Slovakia. In India, occurrences have been reported in volcanic terrains including the Deccan Trap region, although most are small and the grade varies. For use in agriculture the rock is crushed and screened to a chosen particle size, typically between sub-

millimetre powder and a few millimetres, and then applied without further processing or blended with fertilisers, manures or composts.

Effects on soil properties

Cation exchange capacity. Cation exchange capacity (CEC) indicates how many nutrient cations a soil can hold in a form that plants can use. Many coarse soils record very low values. Clinoptilolite and similar zeolites commonly show CEC values several times higher than those of ordinary mineral soils, so even modest additions can raise the CEC of a sandy profile. Because the exchange sites sit mainly inside the framework channels, they are protected from rapid loss and remain active for a long period.

Nutrient retention and fertiliser efficiency. Zeolites hold ammonium strongly. This slows its conversion to nitrate, which is the form most easily leached or lost as gas, and so keeps nitrogen available for longer. A similar benefit is seen with potassium, which would otherwise be lost from light soils. When zeolite is mixed with urea, ammonium salts or animal manure, it can also reduce ammonia volatilisation. The nutrients are not locked away permanently, because plant roots and the soil solution can draw them out again through exchange. In this sense the mineral acts as a buffer or slow-release store rather than a fertiliser itself.

Water retention and infiltration. The internal pores of zeolite particles can hold water, and the added fine material changes the way pores are arranged between soil grains. In sands and loamy sands this tends to raise the volume of water held at field capacity and to extend the period before wilting. The effect is smaller in clays, where water holding is already high, so response depends on texture. Where zeolite is added to heavy soils, any gain is more likely to come from better aggregation and aeration than from extra storage.

Soil reaction and salinity. Many natural zeolites carry calcium and are mildly alkaline, so they can help to raise the pH of acidic soils and to lower the exchangeable aluminium that harms root growth. In sodic or saline soils, calcium-rich zeolite can exchange calcium for sodium and so help to improve structure, but sodium-rich zeolite can have the opposite effect. It is therefore important to know the cation composition of a material before applying it to problem soils.

Contaminants. Zeolites can adsorb heavy metals such as lead, cadmium, copper and zinc, and some radionuclides, through exchange and surface complexation. This has led to their use in the remediation of mine spoil and contaminated sites, where they reduce metal uptake by plants and

lower the amount that moves into drainage water. Their effect on pesticide retention is more variable and depends on the molecule and the surface treatment of the mineral.

Biological activity. The porous surface offers shelter for microorganisms, and the improved retention of ammonium and water can support more stable microbial activity. Reports of increased root growth, nodulation and mycorrhizal colonisation exist, although results are not consistent between soils and crops, and more work is needed to separate direct and indirect effects.

Summary of main benefits and limits

Soil property	Likely effect of zeolite	Where it matters most
Cation exchange capacity	Increases; stable over time	Sandy and eroded soils
Nitrogen and potassium	Reduced leaching and gaseous loss	High-rainfall and irrigated light soils
Water holding capacity	Higher at field capacity	Coarse-textured, rainfed soils
Soil pH and sodium	Depends on the cations the zeolite carries	Acidic, saline or sodic soils
Heavy metals	Reduced availability to plants	Contaminated or mined land

Application and management

Recommended rates differ widely, from a few hundred kilograms to many tonnes per hectare, depending on soil texture, crop, the quality of the zeolite and the goal of the treatment. A common approach is to start at low to moderate rates and to place the material in the root zone, rather than leaving it on the surface, so that it can interact with roots, water and nutrients. Particle size also matters. Fine powders react faster but may be harder to handle, whereas coarse granules are easier to spread and last longer in the profile. Mixing with compost, farmyard manure or fertiliser before application is often recommended, since it combines the exchange function of the mineral with the biological activity of organic matter. Because zeolite is persistent, a single application can continue to act for several seasons, and this helps to offset its initial price.

Constraints and research needs

Several issues restrict wider adoption. Transport costs are high for a low-value bulk product, which makes local deposits much more attractive than imported material. The quality and the exchangeable cation make-up of natural zeolite differ between sources, so a standard specification and a simple test for CEC, particle size and sodium content would be useful. Some field trials have shown only small yield gains, particularly in fertile or fine-textured soils, which suggests that zeolite should be targeted at soils where specific constraints exist rather than used everywhere. There is also a lack of long-term data on its fate, its effect on soil microbial communities and its benefits when combined with different fertiliser and irrigation programmes. Future work should compare locally available zeolites across the main soil groups of India, test them with common crops under both rainfed and irrigated conditions, and calculate the economic return over several seasons. Studies that combine zeolite with biochar, compost or biofertilisers also look promising.

Conclusion

Zeolites offer a stable and multi-purpose route for improving soils that are limited by low exchange capacity, poor water storage or heavy nutrient loss. Their strongest benefits appear in sandy, acidic or degraded soils, where they can raise CEC, conserve nitrogen and potassium, support water supply and reduce the availability of toxic metals. They are best viewed as one part of integrated soil and nutrient management rather than a replacement for organic matter, balanced fertilisation or good irrigation practice. With careful selection of the material and the soil, and with better local evidence on rates and returns, zeolite can become a practical tool for sustainable crop production.

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Volume: 06 Issue No: 10

TRACING INNOVATION TRAJECTORIES IN AGRICULTURE THROUGH ARTIFICIAL INTELLIGENCE TECHNOLOGIES

Article ID: AG-VO6-I10-17

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Introduction

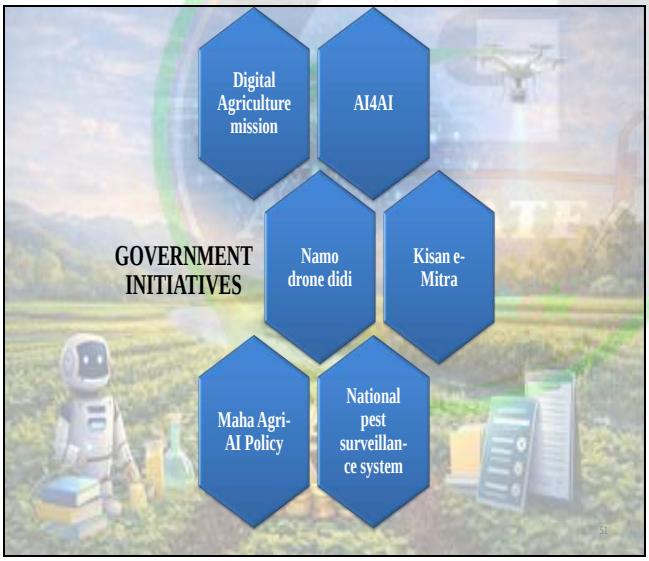
Agriculture today stands at a critical crossroads, as the need for sustainable agricultural production has become more urgent than ever. The global population is projected to increase by nearly 33 per cent, reaching almost 10 billion by 2050 (Anonymous, 2019), thereby exerting immense pressure on existing food systems. Meeting this escalating demand under conditions of shrinking natural resources, climate variability, and environmental degradation necessitates a transition from conventional agricultural practices to smart, efficient, and knowledge-driven farming systems. Such a transformation is essential to ensure food security, enhance resource-use efficiency, and promote long-term agricultural sustainability.

In India, agriculture plays a pivotal role in the national economy and livelihoods, engaging nearly 42 per cent of the workforce while contributing about 18 per cent to the Gross Domestic Product (GDP). The sector is predominantly characterized by small and marginal farmers, who constitute nearly 85 per cent of the total farming community. Despite its significance, Indian agriculture remains highly vulnerable to climatic risks, pest and disease outbreaks, and resource constraints, resulting in substantial economic losses. Crop losses alone are estimated at ₹92,651 crores annually, underscoring the urgent need for timely, precise, and technology-enabled interventions. In this context, the adoption of smart, efficient, and knowledge-driven farming systems becomes crucial to enhance productivity, reduce losses, and improve the resilience and sustainability of Indian agriculture.

GOVERNMENT INITIATIVES SUPPORTING AI IN AGRICULTURE

The Government of India has been actively promoting the adoption of Artificial

Intelligence (AI) in agriculture to improve productivity, provide real-time decision support, and enhance digital services for farmers. Under the **Digital Agriculture Mission**, a unified digital ecosystem is being built that leverages AI, remote sensing, and big data analytics to support crop forecasting, pest alerts, and precision farming. As part of this initiative, more than **48.5 million Farmer IDs** have been issued to enable personalized digital services and AI-based recommendations for farmers. Additionally, AI-powered **national pest surveillance systems** use machine learning to detect and predict pest outbreaks across more than **400 pest species**, helping extension workers provide accurate alerts to farming communities. Government-supported platforms such as **Kisan e-Mitra**, an AI-enabled multilingual chatbot, have addressed **millions of farmer queries** related to crop management, weather, and market prices, increasing accessibility to advisory services (ANYNOMOUS, 2025). These efforts demonstrate the government's emphasis on integrating AI into agricultural planning, real-time advisory systems, and technology adoption to make farming more efficient and data-driven.



Digital Agriculture Mission (2021–2025)

The Digital Agriculture Mission (2021–2025) aims to serve as an integrated platform for implementing multiple digital agriculture projects with a strong farmer-centric focus. The mission seeks to leverage digital technologies, including data analytics, AI, and IT-based tools, to improve agricultural planning, service delivery, and decision-making. A key component of the mission is the development of Digital Public Infrastructure (DPI), which provides a common, interoperable digital framework to support various agricultural services and applications. This infrastructure enables seamless data sharing and efficient delivery of digital solutions to

farmers.Another important initiative under the mission is the Digital General Crop Estimation Survey (DGCES), which uses digital tools and technologies for accurate and timely estimation of crop area and production, thereby improving the reliability of agricultural statistics and policy planning.The mission also emphasizes support for research institutions and state and central governments in IT efforts, encouraging innovation, capacity building, and the adoption of advanced digital technologies in agriculture.Additionally, soil profile mapping is undertaken to provide timely and accurate digital services to farmers. This enables better soil health assessment, precise input recommendations, and improved farm management practices, ultimately contributing to enhanced productivity and sustainability.

The Agri-Stack initiative is a key component of India's digital agriculture strategy and is designed to function as a comprehensive Krishi decision-assistance platform for farmers, extension personnel, and policymakers. It is built on two main pillars that aim to create a robust and integrated digital ecosystem for the agriculture sector. The initiative enables digital authentication of farmers, generation of accurate and real-time data on acreage and crop yields, access to detailed crop maps, and the establishment of strong digital infrastructure to support data-driven and evidence-based agricultural services. Agri-Stack was approved by the Union Cabinet on 2 September 2024 with a total financial outlay of ₹2,817 crore, of which ₹1,940 crore is the central share. Overall, the initiative seeks to digitally transform Indian agriculture by improving precision in decision-making, enhancing efficiency in service delivery, and ensuring a more farmer-centric and transparent agricultural system.

AI for Agricultural Innovation (AI4AI)

The AI for Agricultural Innovation (AI4AI) initiative was launched in August 2020 with the objective of promoting the use of artificial intelligence to address key challenges in the agriculture sector. The initiative was led by the World Economic Forum's Centre for the Fourth Industrial Revolution (C4IR) India, highlighting a strong global–national collaboration framework. The Government of Telangana served as a key partner, with additional support from the Ministry of Agriculture, NITI Aayog, and the Ministry of Electronics and Information Technology (MeitY). The initiative operated on a large scale, involving over 60 partners from the agricultural industry and emerging technology ecosystem, who actively collaborated through weekly workshops conducted between October 2020 and March 2021, fostering innovation, knowledge exchange, and co-creation of AI-driven agricultural solutions.

The AI for Agricultural Innovation (AI4AI) initiative focuses on four key thematic areas to promote the effective use of artificial intelligence in agriculture. These include intelligent crop planning, which supports farmers in making informed decisions on crop selection, sowing time, and resource use; smart farming, which emphasizes the application of AI-enabled technologies such as sensors, automation, and precision tools to improve farm efficiency and productivity; farmgate-to-fork, which aims to enhance transparency, traceability, and efficiency across the agricultural value chain from production to consumption; and data-driven agriculture, which leverages large-scale agricultural data, analytics, and AI models to enable evidence-based decision-making, risk management, and sustainable agricultural development.

Namo Drone Didi

The Namo Drone Didi scheme is an initiative aimed at empowering rural women Self-Help Groups (SHGs) through the use of drone technology in agriculture and promoting women as agri-entrepreneurs providing drone-based services. The programme was launched on 30 November 2023 by the Ministry of Agriculture and Farmers' Welfare and is implemented as part of the DAY-NRLM (Antyodaya Yojana). The scheme targets the coverage of 14,500 women SHGs during the years 2024–25 and 2025–26. Under the scheme, drones are provided to SHGs with 80 per cent central financial assistance, up to a maximum of Rs. 8 lakh per unit. A structured 15-day training programme, guided by the Directorate General of Civil Aviation (DGCA), is offered to women members covering drone operation, maintenance, and agricultural applications. The trained SHGs provide drone rental services to farmers for activities such as crop monitoring, spraying of inputs, and land surveys, thereby enhancing farm efficiency while generating sustainable income opportunities for rural women.

The Namo Drone Didi scheme has generated significant economic and social impacts by improving both agricultural efficiency and women's empowerment. The use of drones helps reduce input costs and enhances agricultural efficiency through precise and timely operations. The programme strengthens women's technical skills, digital literacy, and self-dependency by enabling them to operate and manage drone-based services. It also improves networking and social interaction among rural women by encouraging collective action through Self-Help Groups. Economically, the scheme provides income-generating opportunities, with an estimated annual income of about Rs. 1 lakh per SHG from drone service activities, contributing to improved livelihoods and financial independence.

Table 2 : Selected State-wise Number of Drones Distributed and Drone Pilot Training to Self Help Groups(SHGs) by Lead Fertilizer Company (LFC) under Namo Drone Didi Scheme in India(2023-2024)

States/UTs	No of Drones Distributed and No. of Members of SHGs Given Drone Pilot Training
Andhra Pradesh	108
Assam	28
Bihar	32
Chhattisgarh	15
Goa	1
Gujarat	58
Haryana	102
Himachal Pradesh	4
Jammu & Kashmir	2
Jharkhand	15
Karnataka	**145**
Kerala	51
Madhya Pradesh	89
Maharashtra	60
Odisha	16
Punjab	57
Rajasthan	40
Tamil Nadu	44
Telangana	81
Uttar Pradesh	128
Uttarakhand	3
West Bengal	15
India	**1094**

Source : https://www.indiastat.com

The table presents the state-wise distribution of drones and the number of Self-Help Group (SHG) members trained as drone pilots under the Namo Drone Didi Scheme (2023–2024), implemented through the Lead Fertilizer Company (LFC). It shows how different states have benefited from the scheme in terms of drone allocation and pilot training support. Among the listed states, Karnataka (145) has received one of the highest numbers of drones and training beneficiaries, indicating strong implementation and active SHG participation. Other states with significant distribution include Uttar Pradesh (128), Andhra Pradesh (108), Haryana (102), and Madhya Pradesh (89). States like Assam (28), Goa (4), Jammu & Kashmir (2), and Uttarakhand (3) show comparatively lower numbers, suggesting either limited coverage or phased implementation. Overall, the data reflects regional variation in adoption and highlights the government's effort to promote women-led drone services across multiple states to enhance agricultural efficiency and income generation under the Namo Drone Didi initiative.

Conclusion

Tracing innovation trajectories in agriculture through AI technologies highlights how digital tools and government initiatives are transforming India's farming ecosystem. Programmes such as the Digital Agriculture Mission, AI4AI, Namo drone didiare accelerating the adoption of data-driven farming, enabling applications like pest and disease diagnosis, drone-based crop monitoring, precision input management, automated grading, carbon assessment, and climate-smart advisories. At the same time, challenges including limited digital literacy among smallholders, high implementation costs, poor connectivity, fragmented data systems, and data privacy concerns-continue to slow widespread adoption. Despite these hurdles, the innovation trajectory clearly shows a shift from traditional methods to predictive, efficient, and sustainable farming systems, strengthening resilience, productivity, and technological advancement.

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Volume: 06 Issue No: 10

FROM PETS TO PESTS: THE INVASION RISK OF EXOTIC ORNAMENTAL FISHES IN INDIA

Article ID: AG-VO6-I10-18

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Abstract

Ornamental fishes are valued worldwide for their vibrant colours, distinctive appearances, and commercial importance, supporting livelihoods and contributing to international trade. However, the introduction of exotic ornamental fishes into natural water bodies poses potential threats to native aquatic biodiversity and ecosystem stability. Accidental escapes from culture facilities, flooding, and the intentional release of unwanted aquarium fishes are major pathways of introduction. Once established, non-native species may compete with indigenous fishes for food and habitat, disturb sediments, alter aquatic vegetation, and disrupt ecosystem functioning. India's diverse freshwater ecosystems are particularly important for conserving indigenous aquatic species, making the prevention of biological invasions a significant concern. Inadequate containment and irresponsible aquarium disposal practices can increase the risk of introducing exotic species into natural habitats. Strengthening biosecurity, promoting responsible aquarium management, regulating trade, raising public awareness, and implementing systematic ecological monitoring are essential to minimise invasion risks and support sustainable ornamental fish industry development while protecting India's native aquatic biodiversity.

Introduction

Ornamental fish keeping is a popular hobby worldwide, valued for the beauty, vibrant colours, and diversity of fish kept in aquariums and garden ponds. Often called living jewels, ornamental fishes have aesthetic, recreational, and commercial value. Beyond their popularity as pets, the ornamental fish industry supports livelihoods and generates income for breeders, farmers, collectors, traders, and exporters, particularly in rural and coastal communities. According to UN Comtrade data, the global export value of ornamental fishes in 2021 was approximately $379.1 million, comprising $99.5 million from marine ornamental fishes and $279.6 million from freshwater ornamental fishes (Lafi and Al-Shammari, 2025). These figures highlight the economic significance of the ornamental fish trade, particularly the contribution of freshwater species to the global market.

India possesses rich aquatic biodiversity and considerable potential for developing its ornamental fish industry. The northeastern region, the Himalayan region and the Western Ghats harbour diverse indigenous and endemic ornamental fish species. Indian ornamental fish exports rely substantially on these wild-collected native species, as they contribute around 85% of the country's ornamental fish exports. Despite these natural advantages, India's contribution to global ornamental fish exports remains relatively small, reportedly accounting for less than 1% of the global market. Meanwhile, research institutions are increasingly investigating captive breeding and propagation techniques to promote sustainable production and reduce pressure on natural populations.

In contrast, India's domestic ornamental fish market is strongly influenced by exotic species such as goldfish (*Carassius auratus*), guppies (*Poecilia reticulata*), flowerhorn cichlids and discus (*Symphysodon* spp.), which are popular among aquarium enthusiasts for their vibrant colours, distinctive appearances and commercial value. However, the accidental escape or intentional release of these fishes into natural water bodies may pose ecological risks. Certain non-native species can establish self-sustaining populations, compete with indigenous fishes for food and habitat, disrupt aquatic food webs, and alter ecosystem structure. Therefore, understanding the potential ecological impacts of these exotic species is essential for preventing their introduction into natural habitats and protecting India's native aquatic biodiversity.

Pathways of Introduction and Escape of Ornamental Fishes into Natural Habitats

The ornamental fish industry is a multi-million-dollar global market that supports rural

livelihoods, international trade and aquarium-related businesses worldwide. However, the trade and keeping of ornamental fishes are recognised as potential pathways for the introduction of non-native species into aquatic ecosystems. Padilla and Williams (2004) highlighted the importance of the aquarium trade as a pathway for biological invasions, although the ecological consequences of ornamental fish introductions remain insufficiently understood in many regions. The escape of exotic ornamental fishes into natural habitats may occur either accidentally or intentionally. Accidental escapes commonly occur when fish farms overflow during heavy rainfall and flooding, or when fish enter nearby water bodies through drainage channels. Intentional releases may occur when aquarium owners dispose of unwanted fish, particularly when the fish become too large for their aquariums or difficult to maintain. In some cases, ornamental fishes are also released into natural water bodies as part of religious, cultural or charitable practices (Chan et al., 2019). Although such releases may be motivated by compassion or tradition, they can introduce non-native species into vulnerable aquatic ecosystems.

Open culture systems, including household ponds and abandoned granite quarries, present additional risks when exotic ornamental fishes are reared without adequate containment measures. In Kerala, quarry-based ornamental fish farming has been reported, particularly in the central districts (Krishnakumar et al., 2009). During the monsoon, rainwater accumulates in these quarries, which may be used for ornamental fish culture. When water levels rise and overflow occurs, fish can escape into nearby streams, rivers, and other natural habitats, especially where protective nets, barriers, and screened drainage systems are absent. Similar risks exist in household and farm ponds, where inadequate infrastructure and seasonal flooding can facilitate the escape of cultured fish.

Invasion and Ecological Impacts of Suckermouth Armoured Catfishes

Suckermouth armoured catfishes of the family Loricariidae, commonly known as plecos, are popular aquarium fishes valued for their distinctive appearance and algae-grazing habits. Several species of the genus Pterygoplichthys are native to South American freshwater habitats, including streams, lakes, and wetlands. Through the ornamental fish trade and subsequent introductions, these fishes have established populations in inland waters across several countries. Although used as aquarium cleaners, invasive suckermouth catfishes can compete with native species for food, disturb bottom sediments, degrade aquatic habitats, and affect native fish communities and aquatic insects. Their burrowing activities may contribute to bank erosion,

while their sharp fin spines can injure fish-eating birds, even when the fish are out of water, and make handling difficult and potentially hazardous for humans. Additionally, their spiny bodies and low market value can damage fishing nets, increase sorting costs, and reduce fishers' profitability.

In India, invasive suckermouth catfishes have been documented in several freshwater systems. Biju Kumar et al. (2015) reported *Pterygoplichthys multiradiatus* in drainage systems around Thiruvananthapuram, Kerala, raising concerns about its abundance and potential impacts on native fish communities. Another species, *Pterygoplichthys pardalis*, has been reported from Vandiyur Lake in Madurai, Tamil Nadu. Its occurrence has raised concerns about its interactions with native fish diversity and the challenges associated with managing a species with limited local commercial value. Reports of these fishes being discarded along lake banks after capture also highlight the need for appropriate disposal and management practices (Soundararajan et al., 2015).

Invasion Potential of Introduced Gourami Species

Gouramis are popular ornamental fishes native primarily to Southeast Asia, with some species establishing populations beyond their native range. The three-spot gourami (*Trichopodus trichopterus*) has been reported from areas surrounding Chennai, Tamil Nadu (Daniels, 2006), and Kerala's Vembanad Lake (Krishnakumar et al., 2009). Although its ecological impacts in India remain poorly documented, its opportunistic feeding habits and territorial behaviour may lead to competition with native fishes for food and breeding resources. Its labyrinth organ, which enables atmospheric oxygen uptake, and its bubble-nest breeding behaviour may also favour its survival and reproduction in suitable stagnant waters. Liao and Liu (1989) discussed competition between introduced gouramis and the Chinese barb, *Puntigrus semifasciolatus*, highlighting the need for further research to assess similar ecological interactions in Indian freshwater ecosystems.

Another introduced species, the giant gourami (*Osphronemus goramy*), was brought to Chennai during the nineteenth century and subsequently introduced into other parts of peninsular India, including Maharashtra and Karnataka (Bhimachar et al., 1944). It was also introduced for purposes including the management of aquatic vegetation. As a large omnivorous fish, it consumes both plant and animal matter, potentially influencing aquatic communities through its feeding activities.

Its ability to breathe atmospheric oxygen enables it to tolerate environments with low dissolved oxygen concentrations.

Ecological Consequences of Goldfish Introductions

Goldfish (*Carassius auratus*), one of the most widely kept ornamental fishes worldwide, can adversely affect freshwater ecosystems when introduced into natural habitats. As bottom-feeding omnivores, they disturb sediments while searching for food, increasing water turbidity and releasing accumulated nutrients into the water column. These changes can promote excessive algal growth under favourable conditions, potentially reducing water quality and contributing to oxygen depletion. Increased turbidity may also reduce light penetration, impair the growth of aquatic vegetation, and degrade habitats used by native fishes for feeding and reproduction (Morgan et al., 2005). Furthermore, goldfish may consume the eggs, larvae, juveniles, and adults of native fish species, depending on prey availability, potentially affecting their recruitment and survival.

Conclusion

The growing popularity of exotic ornamental fishes highlights the need to recognise their ecological implications beyond the aquarium trade. Although not all introduced species become invasive, their establishment in natural habitats can create long-term challenges for biodiversity conservation and aquatic ecosystem management. Preventing such invasions is considerably more practical than controlling established populations, which may be difficult, costly, and sometimes ineffective. Therefore, precautionary approaches should be prioritised when introducing, transporting, breeding, and maintaining non-native ornamental species.

In India, strengthening the link between ornamental fish industry development and biodiversity conservation is essential. Improved biosecurity, responsible consumer behaviour, scientific risk assessment, and effective enforcement of existing regulations can collectively reduce the likelihood of exotic fishes entering natural ecosystems. Reliable data on the distribution, establishment, and ecological impacts of introduced species are essential, particularly where evidence from Indian ecosystems remains limited. Collaboration among researchers, fish farmers, traders, aquarium hobbyists, and government agencies is vital for effective monitoring and prevention. Promoting responsible aquarium practices and sustainable trade can help conserve India's native aquatic biodiversity while supporting the ornamental fish industry's economic growth and livelihoods.

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Volume: 06 Issue No: 10

FROM UNEMPLOYMENT TO ENTREPRENEURSHIP: EMPOWERING RURAL YOUTH THROUGH CLIMATE-SMART POLYHOUSE CARNATION CULTIVATION UNDER NICRA

Article ID: AG-VO6-I10-19

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Introduction

Details of the Entrepreneur

Name	**:**	**Sh. Sanjay Kumar Thakur**
Date of Birth / Age	**:**	**16.10.1994 / 31 years**
Address	:	S/O Sh. Krishan Chand Thakur Village & P/O Jarol-Sainji Teh. Balh District Mandi (HP) -175027
Qualification	:	Graduation (IT)
Mobile	:	**7590020005**
KVK	:	Mandi (HP)



Back ground/ Situation

Mr. Sanjay Kumar, a 31-year-old unemployed young farmer owning 22 bighas of agricultural land, is a resident of Village Jarol, Post Office Sainji, Tehsil Sundernagar, District Mandi, Himachal Pradesh. After completing his graduation, he was unable to secure suitable employment. Instead of remaining idle, he chose to pursue agriculture as a dignified means of livelihood and devoted himself wholeheartedly to farming. Like many farmers in the region, Mr. Sanjay Kumar faced serious challenges arising from erratic rainfall, rising temperatures, and increasing climate variability. These challenges resulted in low crop productivity, high labour drudgery, limited access to modern technologies, and heightened vulnerability to climate change. Earlier, he practiced traditional cereal-based farming, cultivating paddy, maize, and wheat, along

with livestock rearing. This farming system provided an annual income of only about ₹70,000, which was low and unstable, making it difficult to ensure economic security.

Determined to improve his economic condition and enhance resilience against climatic risks, Mr. Sanjay Kumar actively sought scientific guidance and innovative farming solutions. Being educated and progressive in outlook, he realized the need for diversification in agriculture to achieve higher and sustainable returns. In the year 2019, he came into contact with Krishi Vigyan Kendra (KVK), Mandi, where he interacted with scientists and expressed his keen interest in adopting agriculture as a means of self-employment.

Recognizing his enthusiasm and potential, scientists from KVK, Mandi visited his village, organized awareness programmes, and motivated farmers, including Mr. Sanjay Kumar, to adopt scientific and protected cultivation practices. Acting upon this guidance, the young farmer underwent specialized training on protected farming at CSK Himachal Pradesh Agricultural University, Palampur, in February 2020. Subsequently, with financial support from the Department of Horticulture, he constructed two polyhouses, each measuring 250 m^2. With continuous technical backstopping and advisory support from scientists of KVK, Mandi, Mr. Sanjay Kumar successfully initiated the cultivation of carnation under polyhouse conditions, marking the beginning of his transformation from an unemployed youth to a confident agri-entrepreneur.

KVK Interventions

Krishi Vigyan Kendra (KVK), Mandi played a pivotal role in transforming Mr. Sanjay Kumar into a successful youth agri-entrepreneur. After his initial interaction in 2019, KVK scientists provided continuous technical guidance through on-campus and off-campus trainings, exposure visits, and advisory services. Awareness camps were organized in the village to sensitize farmers about the benefits of protected cultivation and crop diversification. KVK scientists guided him in site selection, polyhouse design, choice of suitable carnation varieties, planting material procurement, nutrient management, integrated pest and disease management, and post-harvest handling. Regular field visits and timely advisories helped in minimizing production risks and ensured scientific crop management under polyhouse conditions.

Innovation / Initiative

Motivated by scientific guidance and market potential, Mr. Sanjay Kumar adopted protected cultivation of carnation, a high-value floricultural crop, which was a novel initiative in

the area. The shift from traditional cereal-based farming to polyhouse floriculture reflects his innovative and entrepreneurial approach. The polyhouse enabled controlled temperature, humidity, and irrigation, resulting in improved flower quality, higher productivity, and reduced climatic risk. Along with carnation cultivation, he continued growing maize, wheat, paddy, garden pea, onion, and garlic in open fields, thereby ensuring crop diversification, efficient land use, and year-round income generation.

Socio-Economic Impact

The adoption of polyhouse carnation cultivation brought a remarkable improvement in the socio-economic status of the young farmer. In addition to this his annual income increased substantially from ₹70,000/- to 433650 /- a sustainable and significantly higher level, making agriculture a profitable enterprise. The venture generated employment opportunities for local youth and women during activities such as planting, intercultural operations, harvesting, grading, and marketing of flowers. Improved income enhanced his family's standard of living, ensured financial stability, and strengthened his confidence in agriculture as a viable livelihood option.

Farm component	**Number/Area (ha)**	**Input cost (Rs.)**	**Net Income (Rs.)**
Polyhouse cultivation of carnation	500 m^2 (Two units)	75000	250000
Maize, Paddy during Kharif and wheat during *Rabi* season	0.60	15000	25650
Garden pea, Onion and garlic	0.40	25500	78000
Litchi and Kiwi fruit plants (250 No)	0.50	15000	25000
Dairy	1 cows (Sahiwal)	42500	55000
Total		**98000**	**433650**





RAWE students of BSc Agriculture final year of CSKHPKV visited and alloted to him for field exposure



Poly house unit of farmer



Carnation at flowering stage





Harvesting and packaging of Carnation for marketing

Climate Resilience

Protected cultivation of carnation proved to be a climate-resilient intervention for Mr. Sanjay Kumar. The polyhouse system minimized the adverse effects of erratic rainfall, temperature extremes, and pest-disease incidence. Efficient water use through drip irrigation, reduced dependence on weather conditions, and improved input use efficiency contributed to sustainable and resilient farming. The enterprise demonstrated how protected cultivation can help small and marginal farmers adapt to climate change while maintaining productivity and profitability.

Youth Entrepreneurship and Inspiration

Mr. Sanjay Kumar's journey from unemployment to entrepreneurship stands as a motivating example for rural youth. His success highlights the role of education, innovation, and institutional support in transforming agriculture into a respectable and remunerative profession. Today, he serves as a role model for other unemployed youth and farmers in the region, inspiring them to adopt modern technologies and diversified farming systems. His enterprise exemplifies

youth-led agricultural transformation, contributing to sustainable livelihoods, rural employment, and overall agricultural development.

Awards and Recognition

Owing to his innovative approach, successful adoption of protected cultivation and exemplary performance as a young agri-entrepreneur, Mr. Sanjay Kumar has earned recognition at the local level. His polyhouse carnation enterprise has been widely appreciated by fellow farmers, extension officials, and scientists for demonstrating the potential of youth-led, climate-resilient agriculture. He has been showcased by Krishi Vigyan Kendra, Mandi as a progressive and innovative young farmer during farmers' trainings, field days, exposure visits, and awareness programmes. His farm has served as a live demonstration unit for protected cultivation and crop diversification, inspiring many unemployed rural youth and small farmers to adopt polyhouse technology and scientific farming practices. His contributions towards promoting modern agricultural technologies and youth entrepreneurship have positioned him as an emerging role model in the district.

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CLIMATE-SMART SEEDS: BUILDING RESILIENT AGRICULTURE FOR A CHANGING CLIMATE

Article ID: AG-VO6-I10-20

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Introduction

Agriculture is becoming increasingly vulnerable to the effects of climate change. Farmers today face numerous challenges such as rising temperatures, erratic rainfall, prolonged droughts, floods, cyclones, and the spread of new pests and diseases. These extreme weather conditions often reduce crop productivity, threaten farmers' livelihoods and create concerns about long-term food security.

Although practices like improved irrigation, efficient soil management and modern crop production techniques help reduce climate-related risks, the success of any crop begins with one essential input—the seed. A healthy, vigorous seed forms the foundation of a productive crop and plays a vital role in ensuring successful harvests. In this context, **climate-smart seeds** have emerged as an effective solution for building resilient agricultural systems capable of withstanding changing environmental conditions.

Understanding Climate-Smart Seeds

Climate-smart seeds are specially developed crop varieties that can grow successfully under adverse climatic conditions. These seeds possess desirable characteristics that enable crops to tolerate drought, excessive heat, flooding, salinity, pests, and diseases while maintaining satisfactory yields. The primary objective of climate-smart seeds is to provide farmers with

reliable planting material that ensures stable crop production even when weather conditions become unpredictable.

Why Climate-Smart Seeds Are Becoming Essential

Agricultural production depends greatly on climatic factors such as rainfall, temperature, humidity, and seasonal weather patterns. Even small variations in these conditions can influence seed germination, crop growth, flowering, and grain development. As climate change increases the frequency of extreme weather events, farming has become more uncertain than ever before.

Their adoption offers several important advantages:

- Better and more uniform crop establishment.
- Lower chances of crop failure.
- Stable crop yields despite climatic variability.
- Increased confidence among farmers during uncertain weather.
- Improved food production and national food security.

Major Characteristics of Climate-Smart Seeds

Climate-smart seeds are developed to possess one or more beneficial traits depending on the climatic conditions of a particular region. Their important characteristics include:

- High germination percentage.
- Excellent seed vigour for rapid crop establishment.
- Tolerance to drought and moisture stress.
- Ability to withstand high temperatures.
- Resistance to flooding and temporary water logging.
- Salinity tolerance in coastal and salt-affected soils.
- Resistance to major insect pests and plant diseases.
- Efficient utilization of water and nutrients.
- Early maturity that allows crops to escape late-season drought or heat stress.

Climate-Resilient Seed Development in India

India has made remarkable progress in developing crop varieties that can withstand climatic stresses. Over the years, agricultural scientists have released several improved varieties of rice, wheat, maize, pulses, millets, oilseeds and vegetables that perform well under drought, flooding, heat and saline conditions.

For instance, drought-tolerant pearl millet and sorghum varieties have helped farmers in dry regions such as Rajasthan and Karnataka maintain better yields during years of inadequate rainfall. In eastern India, flood-tolerant rice varieties have reduced crop losses caused by seasonal flooding. Likewise, salt-tolerant rice varieties are proving beneficial in coastal areas where seawater intrusion affects agricultural lands. Heat-tolerant wheat varieties are also becoming increasingly important in northern India, where rising temperatures during grain filling often reduce productivity.

The Role of Seed Technology

Developing a superior crop variety is only one part of the process. Farmers receive maximum benefits only when high-quality seeds are produced, tested, certified and distributed efficiently. This is where seed technology plays a crucial role.

A strong seed production system ensures that farmers receive seeds with:

- High genetic purity.
- Excellent physical purity.
- Good germination capacity.
- Strong seed vigour.
- Freedom from seed-borne pests and diseases.
- Proper storage quality that preserves viability until sowing.

Modern Seed Enhancement Technologies

Several seed enhancement techniques have been developed to further improve seed performance under stressful environmental conditions. These technologies increase seedling survival, improve crop establishment and enhance overall productivity.

Seed Priming

Seed priming is a simple but highly effective technique in which seeds are soaked under carefully controlled conditions before sowing. This process activates early metabolic activities within the seed without allowing complete germination.

Primed seeds germinate faster, emerge more uniformly and develop stronger seedlings. They also perform better under drought and heat stress during the initial stages of crop growth, resulting in healthier crop establishment.

Seed Treatment

Seed treatment involves applying fungicides, insecticides, biofertilizers, or beneficial microorganisms to seeds before sowing. This practice protects emerging seedlings from soil-borne and seed-borne diseases while improving nutrient availability during the early growth period.

Healthy seedlings established through seed treatment are generally more capable of tolerating environmental stress throughout the growing season.

Seed Coating

Advanced seed coating technologies cover seeds with protective materials containing micronutrients, biological agents, growth promoters, or moisture-retaining substances. These coatings create a favorable environment around the seed, supporting better germination and stronger seedling growth under adverse conditions.

Precision Seed Production

Precision seed production follows scientific methods to ensure that seeds maintain high genetic purity, uniform quality and excellent health standards. Proper field inspection, isolation, harvesting, processing and storage help deliver reliable seeds to farmers.

By integrating these modern technologies, seed producers can significantly improve the performance of climate-smart seeds and increase farmers' confidence in adopting improved varieties.

Benefits of Climate-Smart Seeds

The use of climate-smart seeds provides numerous economic and agricultural benefits to farmers.

Some of the major advantages include:

- Improved germination and rapid crop establishment.
- Better tolerance to drought, heat, floods and salinity.
- Reduced crop losses under adverse weather conditions.
- Lower dependence on pesticides in resistant varieties.
- More efficient utilization of irrigation water.
- Higher and more consistent crop yields.
- Increased farm profitability.
- Greater resilience against climate-related risks.

When these improved seeds are combined with appropriate crop management practices, farmers can achieve sustainable productivity while minimizing production risks.

Climate-Smart Seeds Must Be Supported by Climate-Smart Farming

Although climate-smart seeds play a vital role in improving crop resilience, they cannot solve every agricultural problem on their own. Their maximum potential is achieved only when they are combined with appropriate climate-smart farming practices. The integration of quality seeds with sustainable crop management helps farmers obtain higher yields while conserving natural resources.

Climate-smart agriculture focuses on increasing productivity, adapting to climate change and reducing environmental impacts. Some important practices include:

- Conservation tillage to minimize soil disturbance.
- Balanced fertilizer application based on crop requirements.
- Integrated nutrient management using organic and inorganic sources.
- Efficient irrigation methods such as drip and sprinkler systems.
- Rainwater harvesting to improve water availability.
- Crop rotation for maintaining soil fertility and reducing pest incidence.
- Integrated pest management to minimize pesticide use.
- Application of organic manures and biofertilizers.
- Weather-based crop planning for timely agricultural operations.

When these practices are adopted together with climate-smart seeds, farmers can improve productivity while using water, nutrients and other inputs more efficiently.

Challenges in the Adoption of Climate-Smart Seeds

Despite their numerous advantages, climate-smart seeds have not yet reached every farming community. Several practical and economic challenges continue to limit their widespread adoption.

Some of the major constraints include:

- Limited awareness among small and marginal farmers about climate-resilient varieties.
- High prices of improved seeds in certain crops.
- Inadequate seed production and distribution systems.
- Shortage of quality seeds during peak sowing seasons.
- Limited access to certified seeds in remote and tribal areas.

- Insufficient knowledge regarding the selection of varieties suitable for local climatic conditions.
- Continuous changes in climate that require regular development of improved crop varieties.

The Important Role of Farmers

Farmers themselves play an equally important role in ensuring the success of climate-smart agriculture. Even the best-performing seed variety cannot produce satisfactory results unless it is managed properly in the field.

Farmers should therefore adopt the following practices:

- Purchase certified seeds from reliable and authorized sources.
- Select crop varieties that are suitable for local climatic conditions.
- Follow the recommended sowing season and seed rate.
- Treat seeds before sowing to protect young seedlings from pests and diseases.
- Practice integrated crop management throughout the growing season.
- Store unused seeds under suitable conditions to maintain their quality.
- Keep themselves informed about newly released climate-resilient varieties through agricultural extension services.

Future *Prospects*

As climate change continues to influence agricultural production, the importance of climate-smart seeds will continue to grow. Scientists are working to develop crop varieties capable of tolerating multiple environmental stresses simultaneously while maintaining high productivity and nutritional quality.

Future climate-smart seeds are expected to possess improved drought tolerance, heat resistance, flood tolerance, better nutrient-use efficiency, enhanced nutritional value and stronger resistance against emerging pests and diseases.

Conclusion

Every successful harvest starts with a good-quality seed. In today's changing climate, selecting the right seed is more important than ever. Climate-smart seeds help farmers overcome problems like drought, floods, high temperatures, salinity and attacks from pests and diseases.These improved seeds provide better germination, stronger seedlings, stable crop yields, and higher farm income.

They also support food security by helping farmers produce reliable harvests even under difficult weather conditions.

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Volume: 06 Issue No: 10

MUSHROOM-DERIVED BIOACTIVE MOLECULES FOR PLANT DISEASE MANAGEMENT: MECHANISMS OF ACTION, BIOCONTROL POTENTIAL AND AGRICULTURAL APPLICATIONS

Article ID: AG-V06-I10-21

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Introduction

Mushrooms are macrofungi that produce visible, hand-collectable fruiting bodies, either above or below ground (Chang and Miles, 1992). Besides their culinary and medicinal importance, mushrooms are valuable sources of bioactive molecules with potential applications in human health and agriculture. Major mushroom metabolites include polysaccharides, proteins, peptides, phenolic compounds, terpenoids and sterols (Raj and Heera, 2025; Dharani et al., 2026).

Plant diseases caused by fungal, bacterial and viral pathogens contribute significantly to crop losses. Although synthetic pesticides remain important in crop protection, concerns regarding environmental pollution, toxicity and persistence have stimulated interest in sustainable alternatives. Mushroom-derived biomolecules have demonstrated antimicrobial activity in laboratory studies and may also promote plant growth and defence responses (Barseghyan et al., 2016; Wu and Kawagishi, 2020). Their combination with conventional fungicides or other biological control agents may provide additional opportunities for integrated disease management (Park et al., 2020; Sun et al., 2022).

This review discusses the major classes of mushroom-derived biomolecules, their proposed mechanisms of action, and their potential applications in managing fungal plant diseases. Particular emphasis is placed on distinguishing laboratory evidence from greenhouse and field validation.

2. Classification of Mushroom-Derived Biomolecules

Mushrooms contain primary biomolecules required for cellular structure and metabolism, together with secondary metabolites that may contribute to ecological interactions. Important constituents include polysaccharides such as α- and β-glucans and chitin; proteins and peptides; lipids and fatty acids; nucleic acids; phenolic compounds; terpenoids and triterpenes; sterols such as ergosterol; and other metabolites, including ergothioneine. Mushrooms also provide vitamins and minerals.

The biological properties of these constituents vary according to mushroom species, cultivation conditions, extraction methods and chemical structure. Although several compounds are recognised for nutritional or pharmacological activities, their potential for agricultural disease management must be established through pathogen-specific experiments.

3. Major Mushroom-Derived Biomolecules in Plant Disease Management

3.1. Polysaccharides

Mushroom-derived polysaccharides, particularly β-glucans, heteropolysaccharides and chitin–glucan complexes, have attracted interest because of their potential antifungal activity and ability to influence plant defence. Their biological effects depend on molecular weight, monosaccharide composition, glycosidic linkages, branching patterns and extraction conditions.

Yang et al. (2024) investigated PFP1-1, a polysaccharide isolated from *Pleurotus ferulae*. Structural characterisation indicated a molecular weight of approximately 23 kDa, with mannose, galactose, glucose and fucose among its constituent sugars. The preparation reportedly inhibited *Rhizoctonia solani* mycelial growth by up to 70% in vitro. In pot experiments, treated cucumber plants showed a reported disease incidence of 22.92%, alongside improved root growth and fresh weight. Changes in superoxide dismutase (SOD), peroxidase (POD) and polyphenol oxidase (PPO) activities were also observed. These results suggest potential direct antifungal and plant defence-related effects, although field efficacy requires further investigation.

The polysaccharide of *Ganoderma lucidum* (GLP) has also been studied for controlling cotton Fusarium wilt. Zhang et al. (2019) reported that foliar spraying, root irrigation and seedling soaking improved cotton growth and disease resistance. Treatments altered POD, SOD and PPO activities, reduced malondialdehyde content and influenced genes associated with jasmonic acid signalling.

Yang et al. (2022) further investigated GLP in wheat and maize. Seed coating with GLP combined with chemical fungicides reportedly achieved more than 75% control of major soil-borne diseases under the experimental conditions. The combined treatment improved disease control in greenhouse and field trials and influenced resistance-associated gene expression. However, the contribution of GLP must be distinguished from that of the fungicide through appropriate treatment comparisons.

Cordyceps militaris polysaccharides have also been reported as potential agents for postharvest disease management in tomato fruits (Zhang et al., 2026). The reported investigation concerns antioxidant enzymes, defence-related enzymes and host responses associated with disease resistance. The original publication should be checked before finalising specific mechanistic claims.

Overall, polysaccharides represent an important group of candidate biomolecules for direct pathogen suppression, host defence stimulation and integration with conventional disease-management practices.

3.2. Phenolic Compounds and Flavonoids

Phenolic compounds are reported in several mushroom species and include phenolic acids and other aromatic molecules. Their composition varies with species, developmental stage, substrate and extraction method. Certain phenolics exhibit antimicrobial activity in laboratory assays, potentially through effects on microbial membranes, enzymes, metal availability and cellular redox balance.

For plant pathology applications, mushroom-derived phenolic-rich extracts should be evaluated against pathogens such as *Colletotrichum* spp., *Fusarium* spp., *Alternaria* spp., *Botrytis cinerea* and *Rhizoctonia solani*. Measurements of mycelial growth, conidial germination, sporulation and disease severity are needed to establish antifungal potential.

Increased phenolic content in treated plants may indicate a biochemical response to treatment or infection. However, such changes alone do not establish induced systemic resistance. Appropriate experiments must demonstrate that the treatment reduces disease and activates relevant host defence responses.

3.3. Terpenoids and Triterpenes

Terpenoids are structurally diverse natural products, and triterpenoids are particularly prominent in the genus *Ganoderma*. These include ganoderic acids and related lanostane-type

compounds. Their structural diversity and biological activities have been reviewed by Liang et al. (2019, 2022).

Some terpenoids have been investigated for effects on microbial membranes, enzymes and cellular processes. Nevertheless, pharmacological activities reported in human or animal systems cannot automatically be extrapolated to plant-pathogenic fungi. Ganoderma-derived triterpenoids should therefore be screened against economically important pathogens using concentration-response assays, followed by greenhouse and field evaluations.

Their development as crop-protection agents requires evidence of antifungal efficacy, crop safety, environmental compatibility, formulation stability and economic feasibility.

3.4. Proteins, Peptides and Lectins

Mushrooms produce proteins and peptides with diverse biological activities. Some have demonstrated antifungal properties in laboratory studies, potentially through interference with fungal cell-wall formation, membrane integrity, enzyme activity or intracellular processes (Wong et al., 2010).

For agricultural applications, candidate proteins should be evaluated against relevant phytopathogenic fungi using standardised assays measuring mycelial growth, conidial germination and disease severity. Their stability under different pH, temperature and formulation conditions also requires investigation. Activity against medically important fungi does not establish efficacy against plant pathogens.

Lectins are carbohydrate-binding proteins reported in genera including *Agaricus*, *Pleurotus*, *Russula* and *Ganoderma* (Singh et al., 2010). Their carbohydrate-recognition properties provide opportunities for studying interactions with biological surfaces. However, carbohydrate binding alone does not demonstrate antifungal activity. Each lectin–pathogen combination requires experimental validation, including assessment of phytotoxicity and effects on beneficial organisms.

3.5. Enzymes and Other Bioactive Metabolites

Chitinases and β-glucanases hydrolyse structural components of fungal cell walls and may contribute to pathogen suppression. The roles of chitinolytic microorganisms and related enzymes in biological control have been discussed by Martínez-Hidalgo et al. (2019) and Das et al. (2024). However, evidence concerning microbial chitinases should not be interpreted as direct

proof of the activity of mushroom-derived enzymes. Their origin and contribution must be established experimentally.

Mushrooms also contain sterols, organic acids, meroterpenoids and other low-molecular-weight metabolites. Bioassay-guided fractionation can identify compounds associated with antifungal activity. Analytical techniques such as liquid chromatography–mass spectrometry and nuclear magnetic resonance spectroscopy can support chemical identification, while testing purified compounds helps establish the relationship between chemical identity and biological activity (Liang et al., 2022).

4. Mechanisms of Action Against Fungal Plant Pathogens

4.1. Direct Antifungal Activity

Mushroom-derived biomolecules may inhibit mycelial growth, spore germination or pathogen development by affecting membrane integrity, enzyme activity, metabolism or other essential cellular processes. Chitinases and glucanases may also weaken fungal cell walls through hydrolysis of their structural components.

Nevertheless, inhibition of radial growth in an agar assay demonstrates activity only under the tested conditions. It does not identify the molecular target or establish disease control in plants. Microscopy, membrane-integrity assays, biochemical measurements and molecular analyses are required to substantiate proposed mechanisms.

4.2. Activation of Host Defence Responses

Some mushroom-derived preparations are associated with changes in defence-related enzymes, phenolic accumulation and defence-gene expression. Enzymes such as POD, SOD, PPO and catalase participate in plant redox regulation, while chitinases and β-1,3-glucanases may contribute to defence against fungal pathogens.

However, enzyme activity changes alone cannot establish the complete defence-signalling pathway or prove induced systemic resistance. Stronger evidence requires disease measurements, suitable controls and experiments that distinguish direct pathogen inhibition from host-mediated protection.

4.3. Modulation of Oxidative Stress

Reactive oxygen species participate in plant defence but can also damage host tissues when accumulated excessively. Antioxidant enzymes help regulate oxidative stress, and

mushroom-derived preparations may influence these responses. The biological significance of such changes depends on the crop–pathogen interaction and treatment.

Consequently, antioxidant enzyme measurements should be interpreted alongside disease severity, pathogen growth and host injury rather than used independently as evidence of resistance.

4.4. Synergistic Effects and Integrated Disease Management

Mushroom-derived biomolecules may complement conventional fungicides and biological control agents. The GLP studies discussed above provide a basis for investigating combinations with chemical fungicides. However, combined treatments should be compared with the biomolecule alone, fungicide alone and untreated control.

Compatibility, phytotoxicity, persistence and disease suppression must be assessed. Synergy should only be claimed when the observed combined effect exceeds the expected effect under an appropriate experimental model.

5. Agricultural Applications

5.1. Soil-Borne Disease Management

Mushroom polysaccharides and other candidate biomolecules may be evaluated as seed treatments, root-zone applications or soil-directed formulations against pathogens such as *Fusarium* spp. and *R. solani*. The PFP1-1 study provides an example of laboratory and pot-level evidence. Further work should establish reproducibility across soils, cultivars and environmental conditions and determine effects on beneficial soil microorganisms.

5.2. Foliar Disease Management

Mushroom-derived preparations could be investigated as preventive sprays or post-infection treatments against diseases caused by *Colletotrichum*, *Alternaria* and *Botrytis*. Preventive inhibition of spore germination does not necessarily indicate curative activity against established infections. Experiments should measure disease incidence, severity, sporulation and crop injury, with comparison against an appropriate standard treatment.

5.3. Postharvest Disease Management

Mushroom biomolecules may have potential as fruit-surface treatments or components of edible coatings to reduce postharvest decay. Research should measure disease incidence, lesion development, firmness, weight loss, sensory quality and storage life. Food-contact safety and

residue requirements must also be considered. The reported *C. militaris* polysaccharide study should be discussed in detail only after its methods and results have been verified.

5.4. Seed Treatment and Integrated Management

Seed coating offers a possible means of delivering mushroom-derived polysaccharides near developing seedlings. The wheat and maize results reported by Yang et al. (2022) suggest that combined treatments warrant further investigation. Appropriate controls are essential to distinguish the contribution of the mushroom preparation from that of the fungicide.

At present, mushroom-derived biomolecules are best considered potential components of integrated disease management rather than universal replacements for conventional fungicides.

6. Formulation, Limitations and Future Perspectives

The composition of mushroom extracts depends on species, strain, substrate, tissue, extraction solvent and processing conditions. Standardisation should therefore include chemical characterisation, biological activity and batch-to-batch consistency. Total polysaccharide or phenolic content alone does not identify the active constituents.

Formulation strategies, including protective carriers and encapsulation, may improve stability and delivery. However, their benefits must be tested under realistic agricultural conditions. Natural origin does not guarantee crop safety; phytotoxicity, non-target effects, environmental persistence and possible residues must be evaluated.

Future research should prioritise active-compound identification, structure–activity relationships, elucidation of antifungal mechanisms, formulation development and replicated greenhouse and field trials. Economic feasibility, yield effects, compatibility with beneficial microorganisms and performance across locations and seasons are also essential. These studies will determine whether mushroom-derived biomolecules can provide reliable and practical disease-management benefits.

Conclusion

Mushroom-derived polysaccharides, phenolic compounds, triterpenoids, proteins, peptides, lectins, enzymes and other metabolites represent a diverse source of candidates for sustainable plant disease management. Their potential effects include direct inhibition of fungal growth, interference with pathogen development and modulation of host defence responses.

Polysaccharides have shown encouraging results in laboratory, pot and, in some cases, combined-treatment field studies. Nevertheless, evidence from medicinal or biochemical

research alone is insufficient to establish efficacy against fungal plant pathogens. Identification of active compounds, validation of mechanisms, formulation optimisation, crop-safety assessment and replicated field trials are essential before practical recommendations can be made. With rigorous validation, selected mushroom-derived biomolecules may contribute to integrated crop-protection strategies.

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Volume: 06 Issue No: 10

PARASITIC HELMINTHS AND THEIR MANAGEMENT IN BACKYARD POULTRY

Article ID: AG-VO6-I10-22

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Abstract

Backyard poultry farming is an age-old practice widely adopted in rural areas, particularly under free-range and semi-intensive systems, and contributes significantly to household income and livelihood security. However, the productivity of backyard poultry is often affected by parasitic infections, especially internal parasites. The free-ranging system increases their exposure to infective stages of parasites and/or intermediate hosts such as earthworms, beetles, flies, ants, grasshoppers and snails. Helminths of poultry include nematodes, cestodes and trematodes, which may affect different organs such as the crop, proventriculus, gizzard, intestine, caeca, trachea and oviduct. Important nematodes include *Capillaria* spp., *Ascaridia galli*, *Heterakis gallinae* and *Syngamus trachea*, while cestodes such as *Raillietina* spp., *Davainea proglottina*, *Choanotaenia infundibulum* and *Hymenolepis carioca* may cause poor growth, emaciation, enteritis and, in severe infections, mortality. Trematodes, particularly *Prosthogonimus* spp., can cause serious reproductive disturbances and reduced egg production in affected hens. Effective management of parasitic helminths include periodic deworming, improved sanitation, regular disinfection, prevention of overcrowding, maintenance of clean and dry feeding and watering areas, isolation of newly introduced birds and reduction of exposure to intermediate hosts. Awareness and timely management of parasitic infections are therefore essential to maintaining the health and productivity of backyard poultry and improving the livelihood security of rural farmers.

Backyard poultry production is an age-old practice which comprises rearing of indigenous birds in free range or semi-intensive conditions. This is a common practise in rural India because it involves less initial investment but higher economic gain. The feed cost is negligible due to better utilization of agricultural by-products and leftover feed and grains. Not only is there a growing demand for desi chicken eggs and birds but they also contribute to an additional income to the family. However, parasitic diseases continue to be of great importance in deep-litter and free-range systems and contributes significantly to the low productivity. Internal parasitism is usually more insidious because it is hardly noticeable as specific disease condition, but are a hurdle to successful poultry raising. Internal parasites live inside their hosts and deprive them of nutrients and consequently affecting their productivity. Helminths of poultry include roundworms or nematodes, tapeworms or cestodes, flukes or trematodes.

Nematodes of poultry

Nematodes, are elongate, cylindrical, unsegmented which range from mm to several inches in length. They are aquired either through ingestion of infective stage of parasite or intermediate host such as insects, beetles, cockroaches which harbour the infective stage of parasite.

Nematodes of Proventriculus and gizzard

Domestic fowls are susceptible to infection with at least three species of crop worms, namely, *Capillaria annulata*, *C. contorta*, and *Gongylonema ingluvicola*. The lesions caused by the crop worms are thickening of the wall and an enlargement of the glands of the crop and esophagus. The proventriculus, or true stomach, is the site of infection by two parasitic roundworms, *Dispharynx spiralis* and *Tetrameres americana*. Tumors are usually formed at the site of the attachment of the worms. In heavy infections the walls of the proventriculus become so swollen that the cavity is almost obliterated. *Cheilospirura hamulosa* requires an intermediate host like grasshoppers and beetles for its complete development. In heavy infections a large part of the posterior portion of the gizzard may become enlarged and frequently loses its natural shape.

Intestinal nematodes of poultry

One of the commonest and perhaps the most frequently seen of the parasitic roundworms of poultry is the intestinal roundworm of chickens, *Ascaridia galli*. Chickens of 3 to 4 months of age or older are quite resistant to parasitism with *Ascaridia galli*. Heavily infected birds have

been found to suffer from blood loss, reduced blood-sugar level, droopiness, emaciation, and diarrhoea. The caecal worm of poultry, *Heterakis gallinae* occurs commonly in the ceca of chickens, turkeys, and possibly other domestic fowls. It is transmitted by ingestion of eggs and acts as a carrier of the causative agent of blackhead disease (*Histomonas meleagridis*).

Tracheal worms of poultry

Gapeworm infection, is caused by *Syngamus trachea* that lives in trachea. Fowls become infected by swallowing either the infective eggs or the infected earthworm. The worms tend to block the trachea of young poultry, causing them to sneeze, cough, and gape for air. An extensive irritation of the mucous lining of the windpipe results from the bloodsucking activities of the gapeworms, and coughing is apparently caused by irritation due to their presence. Affected birds become weak, emaciated, with head drawn back against the body and gasping air. Sudden death is due primarily to suffocation caused by the mechanical obstruction of the trachea by the rapidly growing worms and the accumulation of secreted mucus.

Cestodes of poultry

Poultry reared under free range conditions are likely to be infected with cestodes (tapeworms). All tapeworms of poultry have indirect life cycles with intermediate hosts such as earthworms, beetles, flies, ants or grasshoppers. The intermediate hosts are essential to perpetuate the life cycle and infections are therefore rare in cage rearing systems. *R. echinobothrida* are found in chicken, turkey, guineafowl and pigeon, whereas *R.cesticillus* is common in domestic chickens. Of the three species *R. echinobothrida* is the most pathogenic causing nodules and hyperplastic enteritis. Infections with *R. tetragona* are less pathogenic but causes reduced weight gain. *D. proglottina* is one of the highly pathogenic species, causing haemorrhagic duodenitis. *Choanotaenia infundibulum* infections occur in fowls and turkeys in most parts of the world that are found attached to the small intestine, adult tapeworms are only moderately pathogenic and causes weight loss. *Hymenolepis carioca* is a parasite of small intestine of fowl and is known to cause catarrhal enteritis, diarrhoea even mortality in case of heavy infections with thousands of adult worms in the intestine.

Trematodes of poultry

Flukes, or trematodes, are small, flattened, unsegmented worms, usually inhabiting the intestinal tract, lung, liver, or oviduct. They are mainly transmitted indirectly through intermediate hosts such as snails, dragonfly naids, and mollusks. One of the most important fluke

is *Prosthogonimus* commonly referred to as oviduct fluke that occurs in **chicken, ducks, turkey and other domestic and wild birds**. S**evere infections can be lead to impaired egg laying,** smooth shelled eggs, or eggs with no shells. The cuticular spines of the flukes damage the bird's oviduct and affect peristaltic motility. Characteristic symptoms include lime discharge from the cloaca that may contain flukes, and subsequent soiling of the feathers around the vent. Heavily affected birds lose appetite and refuse feeding, become listless and thirsty, walk abnormally, show difficulty in breathing and have a tense and pendulous abdomen. Therefore, effective control of helminth infections is important for maintaining the health, growth and productive performance of backyard poultry.

Treatment and Control of Parasitic Helminths

Effective management of helminth infections in backyard poultry requires a combination of appropriate anthelmintic treatment and preventive flock-management practices. Deworming should be undertaken based on the type of parasite involved and the administered as per recommended dose. Anthelmintics such as piperazine, fenbendazole are used to treat nematode infections, while specific cestocidal such as praziquantel, has been reported to be effective against cestodes. However, treatment should be combined with measures to reduce exposure to intermediate hosts such as ants, beetles, flies, earthworms and other insects to prevent reinfection. Birds should be provided with a clean, dry and well-drained range, while feeders and drinkers should be kept clean and protected from faecal contamination. Regular removal of droppings, cleaning and disinfection of poultry houses and avoidance of overcrowding help reduce the accumulation of infective parasite stages. Newly introduced birds should be kept separate before mixing with the existing flock. Periodic monitoring of flock health and timely parasitological examination can help detect infections early and facilitate appropriate treatment.

Conclusion

Parasitic helminths cause considerable economic loss in backyard poultry production. The free-ranging nature of backyard birds increases their exposure to infective stages and intermediate hosts, making nematode, cestode and trematode infections relatively important in these production systems. Heavy infections can adversely affect growth, health, egg production and overall productivity. Effective control requires an integrated approach combining anthelmintic treatment with managemental practices towards improved livelihood security for rural poultry rearers.

Volume: 06 Issue No: 10

VEGETABLE GRAFTING: A CLIMATE-SMART SOLUTION TO DROUGHT STRESS

Article ID: AG-VO6-I10-23

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Introduction

Drought is emerging as one of the most serious threats to agricultural production across the globe. In India, irregular rainfall patterns, prolonged dry spells, and increasing temperatures are causing frequent water scarcity, especially during critical crop growth stages. Vegetable crops, being highly sensitive and water-demanding, are among the first to suffer under drought stress. Even short-term moisture stress can lead to reduced plant growth, flower drop, poor fruit set, and significant yield losses. With climate change intensifying drought events, it has become essential to adopt innovative and sustainable approaches to maintain vegetable productivity.

Among the various drought mitigation strategies, **vegetable grafting** has gained attention as a promising climate-smart technology. By combining high-yielding varieties with stress-tolerant root systems, grafting offers an effective means of improving drought resilience in vegetable crops.

What is grafting?

Grafting is an ancient horticultural technique in which two plant parts with different genetic traits are physically joined to form a single plant. The lower part, called the **rootstock**, is usually selected from wild or closely related species because of its tolerance to biotic stresses (pathogens), abiotic stresses (drought, salinity) and strong plant vigour. The upper part, known as the **scion**, is chosen for desirable horticultural traits such as high yield and superior fruit quality (Ulas *et al.*, 2025).

Vegetable grafting is widely practiced in crops of the **Solanaceae** and **Cucurbitaceae** families to improve stress tolerance and overall crop performance.

Mechanisms of Drought Tolerance in Grafted Vegetables

The effectiveness of grafting depends on factors such as crop species, grafting method, stress severity, and compatibility between the rootstock and scion. By using stress-tolerant rootstocks, grafted plants exhibit improved adaptation through multiple physiological and biochemical mechanisms.

1. ***Improved water uptake and transport***

A major advantage of grafting under drought is the development of a stronger and deeper root system. Drought stress reduces root biomass and limits soil water movement to roots. Also, drought-resistant rootstocks enhance root traits such as diameter, volume, and length, improving hydraulic conductivity and enabling better extraction of soil moisture (Zia *et al*. 2021).

2. ***Enhanced Water Use Efficiency and Osmotic Balance***

Grafting drought-sensitive cultivars onto tolerant rootstocks improves water use efficiency (WUE), enabling plants to maintain growth and yield under limited irrigation. Grafted plants also exhibit better osmotic adjustment through increased production of osmolytes and metabolites, which enhances water retention and helps maintain cell turgor during drought stress (Ozturk *et al*. 2021).

3. ***Hormonal regulation and stress signalling***

Plant hormones play a central role in drought adaptation of grafted vegetables. Key phytohormones involved include abscisic acid (ABA), auxins (IAA), cytokinins, gibberellins, ethylene, and jasmonic acid. **ABA**, transported from rootstock to scion, regulates stomatal closure and reduces water loss during drought while **IAA**, produced in scion leaves, promotes lateral root formation and improves root development in rootstocks This root-to-shoot signalling enhances drought tolerance through better stomatal control and root system efficiency (Nie and Wen 2023).

4. ***Strengthen antioxidant defence system***

Drought stress induces oxidative damage through the accumulation of reactive oxygen species (ROS). Grafted plants show increased activity of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), and ascorbate peroxidase

(APX), which reduce membrane damage and protect photosynthetic machinery (Dubey *et al*. 2021).

5. *Improved Growth and Yield Stability Under Drought*

Drought reduces nutrient mobility in the soil, limiting uptake by plants. Rootstocks with strong absorption capacity help grafted plants maintain nutrient supply even under moisture stress, supporting growth and productivity (Nie and Wen 2023).

Drought tolerant rootstocks in vegetable crops

Selection of drought-tolerant rootstocks is crucial in grafting, as they enhance root vigour, water uptake, and stress resilience. Commonly used rootstocks in vegetables are as follows:

Vegetable Crop (Scion)	**Common Drought-Tolerant Rootstocks**
Tomato (*Solanum lycopersicum*)	*Solanum pennellii*, *S. pimpinellifolium*, *S. habrochaites*, hybrids like 'Maxifort', 'Beaufort'
Brinjal/Eggplant (*Solanum melongena*)	*Solanum torvum*, *S. incanum*, *S. sisymbriifolium*
Capsicum/Pepper (*Capsicum annuum*)	*Capsicum chinense*, *C. baccatum*, tolerant lines like 'Niber'
Watermelon (*Citrullus lanatus*)	*Lagenaria siceraria* (bottle gourd), *Cucurbita moschata*, squash hybrids (*C. maxima* × *C. moschata*)
Cucumber (*Cucumis sativus*)	*Cucurbita moschata*, *C. maxima*, squash hybrids, *Luffa cylindrica*
Melon (*Cucumis melo)*	*Cucurbita moschata*, *C. maxima*, *Benincasa hispida* (ash gourd)

Challenges

- Higher cost of grafted seedlings
- Requirement of skilled labour and nursery infrastructure
- Compatibility issues between scion and rootstock
- Limited availability of suitable rootstocks in some crops

Conclusion

Drought stress is a major constraint in vegetable production, threatening yield, quality, and farmer livelihoods. Vegetable grafting offers an innovative and climate-smart solution by

combining high-yielding scions with drought-tolerant rootstocks. Through improved root systems, better water use efficiency, hormonal regulation, and enhanced stress tolerance, grafted vegetables perform better under water-limited conditions.

Promoting grafting technology along with other water-saving practices can strengthen the resilience of vegetable farming systems and ensure sustainable production in the face of climate change.

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Volume: 06 Issue No: 10

SALT STRESS: ITS CAUSES, TYPES, MECHANISM AND ITS MITIGATION

Article ID: AG-VO6-I10-24

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Introduction

Salt stress is the adverse effect produced in plants when excessive soluble salts accumulate in the soil or irrigation water. It is one of the major abiotic stresses, particularly important in arid and semi-arid regions. The major salts responsible for salinity include NaCl, Na_2SO_4, $CaCl_2$, $MgCl_2$, $NaHCO_3$ and Na_2CO_3. Among these, sodium (Na^+) and chloride (Cl^-) are particularly important because they can accumulate to toxic concentrations in plant tissues.

Salt stress generally affects plants through two major components:

1. **Osmotic stress** – high salt concentration around roots reduces the availability of water to plants.
2. **Ionic stress** – excessive uptake and accumulation of Na^+ and Cl^- disturb cellular metabolism and cause toxicity.

Types of Salt Stress: Salt stress can be classified in several ways.

A. Based on the nature of soil salinity

1. Saline stress

- Caused mainly by accumulation of soluble salts.
- Electrical conductivity of the soil saturation extract is generally **>4 dS m^{-1}**.
- Sodium toxicity may or may not be severe.

2. Sodic/alkali stress

- Associated with excessive exchangeable sodium.
- Causes deterioration of soil structure and poor water infiltration.
- High pH is commonly associated with sodic soils.

3. Saline-sodic stress

- Both soluble salts and exchangeable sodium are present at high levels.
- Can produce both osmotic and soil-structural problems.

B. Based on duration

- **Temporary salt stress:** occurs for a short period, such as after irrigation with saline water.
- **Chronic salt stress:** persists for a long period because salts continuously accumulate in the root zone.

C. Based on salt composition

- **Chloride salinity** – dominated by Cl^- salts.
- **Sulfate salinity** – dominated by sulfate salts.
- **Carbonate/bicarbonate salinity** – associated with bicarbonates and carbonates.
- **Mixed salinity** – several salts occur together.

Causes of Salt Stress: Salt stress develops when salts enter the soil faster than they are removed.

Major causes

1. Irrigation with saline water
2. Poor-quality groundwater
3. High evaporation in arid and semi-arid climates
4. Inadequate drainage
5. High water table
6. Sea-water intrusion in coastal areas
7. Excessive use of chemical fertilizers
8. Natural weathering of salt-containing parent material
9. Accumulation of salts through capillary rise
10. Improper irrigation practices
11. Use of saline drainage water
12. Low rainfall, which reduces natural leaching of salts.

Particularly important in arid regions: In Rajasthan and other dry regions, high evaporation + inadequate rainfall + saline irrigation water + poor drainage can cause rapid accumulation of salts in the root zone.

Mechanism of Salt Stress: Salt stress affects plants through a sequence of physiological and biochemical processes.

Step 1: Salt accumulation in soil

Excess Na^+, Cl^- and other ions accumulate in the root-zone soil solution.

↓

Step 2: Reduction in soil water potential

The high concentration of dissolved salts decreases the **osmotic potential** of the soil solution.

↓

Step 3: Reduced water uptake

Roots find it more difficult to absorb water, even when the soil appears moist.

↓

Step 4: Osmotic stress

Plants experience physiological drought, resulting in:

- Reduced cell expansion Stomatal closure
- Reduced photosynthesis Reduced growth

↓

Step 5: Ion uptake and accumulation

Na^+ and Cl^- enter plant tissues through transport systems.

↓

Step 6: Ionic imbalance

Excess Na^+ interferes with uptake and utilization of essential nutrients such as:

- K^+ Ca^{2+} Mg^{2+} NO_3^- PO_4^{3-}

↓

Step 7: Cellular toxicity

High concentrations of Na^+ and Cl^- disturb:

- Enzyme activity Membrane integrity Protein synthesis
- Photosynthesis Cellular metabolism

↓

Step 8: Oxidative stress

Salt stress increases the production of **reactive oxygen species (ROS)** such as:

- Superoxide radicals Hydrogen peroxide Hydroxyl radicals

These can damage lipids, proteins, pigments and nucleic acids.

Step 9: Growth and yield reduction: Ultimately, severe salt stress causes:

- Leaf injury Premature senescence Poor flowering
- Reduced fruit/seed formation Reduced yield Plant death in sensitive species.

Effects of Salt Stress on Plants

A. Effects on water relations

- Decreases soil water potential. Reduces root water absorption.
- Causes physiological drought. Reduces relative water content.
- Reduces cell turgor.

B. Effects on germination

High salinity can:

- Delay seed germination. Reduce germination percentage.
- Reduce seedling emergence. Reduce seedling vigor.
- Cause abnormal root development.

C. Effects on roots

- Reduced root elongation. Reduced root biomass.
- Reduced root branching. Root cell injury.
- Altered root-to-shoot ratio.

D. Effects on shoots

- Reduced plant height Reduced leaf area Reduced biomass.
- Leaf rolling Leaf drying and necrosis Premature leaf senescence.

E. Effects on photosynthesis

Salt stress causes:

- Stomatal closure Reduced CO_2 uptake
- Chlorophyll degradation Damage to chloroplasts
- Reduced photosynthetic rate

F. Nutritional effects

Excess Na^+ and Cl^- interfere with the uptake of essential nutrients, especially:

- K Ca Mg N P

A particularly important indicator of salt tolerance is the plant's ability to maintain a high **K^+/Na^+ ratio**.

G. Biochemical effects : Salt stress increases:

- ROS production Lipid peroxidation

- Membrane damage Protein degradation

Plants respond by increasing protective compounds such as:

- Proline Soluble sugars
- Glycine betaine Antioxidant enzymes

H. Effects on yield: Severe salinity can reduce:

- Grain yield Fruit yield Seed production
- Fruit quality Oil production Biomass production.

Effects of Salt Stress on Soil

Salt stress is closely associated with deterioration of soil quality.

1. Increased soil electrical conductivity: Accumulation of soluble salts increases **EC**, which indicates soil salinity.

2. Reduced soil water availability: High salt concentration reduces the amount of water that plants can physiologically obtain.

3. Soil structure deterioration: In sodic soils, excessive Na^+ causes clay dispersion and destroys stable soil aggregates.

4. Reduced infiltration: Dispersed soil particles can block soil pores, reducing water movement.

5. Reduced hydraulic conductivity: Water moves slowly through saline/sodic soils, particularly when soil structure has deteriorated.

6. Nutrient imbalance: High salt concentrations interfere with nutrient availability and uptake.

7. Increased soil Ph: Sodic/alkali soils may have very high pH, sometimes **above 8.5**.

8. Reduced microbial activity: Severe salinity can suppress beneficial soil microorganisms and nutrient cycling.

9. Reduced soil fertility and productivity: Long-term salinity can make agricultural land progressively less productive.

Mitigation of Salt Stress

Salt stress can be managed through **soil, water, crop and biological management**.

A. Soil management

1. Leaching: Apply good-quality irrigation water in sufficient quantity to move soluble salts below the root zone.

2. Drainage: Provide adequate surface and subsurface drainage to prevent salt accumulation.

3. Gypsum application: Gypsum (**$CaSO_4 \cdot 2H_2O$**) is particularly useful in **sodic soils** because Ca^{2+} replaces exchangeable Na^+ on soil particles.

4. Addition of organic matter: Farmyard manure, compost and other organic materials can improve:

- Soil structure Water infiltration Microbial activity Root growth

5. Mulching: Mulches reduce evaporation and therefore help reduce upward movement and accumulation of salts.

B. Water management

- Test irrigation water before use.
- Use good-quality water whenever possible.
- Avoid excessive irrigation with saline water.
- Maintain appropriate irrigation intervals.
- Prevent waterlogging.
- Use drip irrigation where appropriate.
- Ensure effective drainage.

C. Crop management

1. Salt-tolerant varieties: Use cultivars selected for tolerance to the salinity level of the field.

2. Proper crop selection: Select crops according to soil salinity.

3. Seed priming: Priming with suitable substances can improve germination and early seedling establishment under salinity.

4. Foliar application: Appropriate foliar application of certain nutrients or protective compounds may improve plant tolerance.

5. Balanced fertilization: Maintain adequate levels of K, Ca, N and other essential nutrients.

D. Biological approaches: Beneficial microorganisms such as:

- **Arbuscular mycorrhizal fungi (AMF)**
- **Plant growth-promoting rhizobacteria (PGPR)**

may improve plant growth and nutrient acquisition under saline conditions.

E. Breeding and biotechnology: Salt tolerance can be improved through:

- Conventional breeding Selection of tolerant genotypes
- Molecular breeding Marker-assisted selection
- Biotechnology

Important tolerance mechanisms include:

- Na^+ exclusion
- Maintenance of K^+/Na^+ balance
- Improved antioxidant defense.
- Na^+ compartmentation in vacuoles
- Osmotic adjustment

Classification of Plants According to Salt Tolerance

Plants can broadly be classified into four groups. **The exact tolerance level varies with species, variety, growth stage and salt composition**, so these categories are approximate.

Category	General response to salinity	Examples
Salt-resistant / highly tolerant	Can grow and produce reasonably well under high salinity	Barley, date palm, cotton, sugar beet, quinoa
Salt-tolerant / tolerant	Can withstand moderate-to-high salinity with relatively limited injury	Wheat, sorghum, pearl millet, some grasses
Moderately tolerant	Growth and yield decline as salinity increases	Maize, soybean, tomato, potato
Salt-susceptible / sensitive	Strong growth reduction and injury at relatively low salinity	Bean, onion, carrot, common bean, many fruit crops

A. Salt-resistant / highly salt-tolerant plants

These plants possess strong mechanisms for maintaining growth under high salt concentrations.

Examples:

- Barley (*Hordeum vulgare*)
- Sugar beet (*Beta vulgaris*)
- Quinoa (*Chenopodium quinoa*)
- Date palm (*Phoenix dactylifera*)
- Cotton (*Gossypium* spp.)

B. Salt-tolerant plants: These can tolerate moderate or moderately high salinity.

Examples: Wheat, Sorghum, Pearl millet and Some forage grasses

C. Moderately salt-tolerant plants

These plants can tolerate moderate salinity but show measurable reductions in growth and yield as salinity increases.

Examples: Maize, Tomato, Potato and Soybean

D. Salt-susceptible plants

These are adversely affected even at comparatively low levels of salinity.

Examples: Common bean, Onion, Carrot and Many sensitive fruit and vegetable crops

Important: Salt tolerance is not an absolute characteristic. A crop may be tolerant during one growth stage but sensitive during another. Germination and early seedling stages are often particularly sensitive.

Important Mechanisms of Salt Resistance/Tolerance

Salt-tolerant plants survive salinity by employing several mechanisms:

1. Na^+ exclusion: Roots restrict the movement of excessive Na^+ into the shoot.

2. Ion compartmentation: Na^+ and Cl^- can be stored in vacuoles, preventing toxic concentrations in the cytoplasm.

3. Maintenance of K^+/Na^+ ratio: Plants maintain adequate K^+ while restricting excessive Na^+ accumulation.

4. Osmotic adjustment: Accumulation of compatible solutes such as **proline, glycine betaine and soluble sugars** helps maintain cell water status.

5. Antioxidant defense: Enzymes such as:

- Superoxide dismutase (SOD) Catalase (CAT)
- Ascorbate peroxidase (APX) Glutathione reductase (GR)

help protect cells from oxidative damage.

6. Morphological adaptation: Some tolerant plants develop:

i. Extensive root systems ii. Succulent leaves iii. Salt glands

iv. Salt bladders v. Improved water-use efficiency.

Conclusion

Salt stress is an important abiotic stress caused by excessive accumulation of soluble salts, particularly Na^+ and Cl^-, in the soil. It is especially serious in arid and semi-arid agricultural regions. The major effects occur through osmotic stress and ionic toxicity. Salt stress reduces water uptake, causes nutrient imbalance, disrupts photosynthesis, increases oxidative stress and ultimately reduces plant growth and yield. It can also deteriorate soil structure, particularly under sodic conditions. Effective management requires an integrated approach involving good-quality irrigation water, proper drainage, salt leaching, gypsum where appropriate, organic amendments, mulching, balanced fertilization, salt-tolerant cultivars, suitable irrigation methods and biological approaches. The ability of plants to exclude Na^+,

maintain a favorable K^+/Na^+ ratio, compartmentalize toxic ions, perform osmotic adjustment and activate antioxidant defenses determines their degree of salt tolerance.

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: 10

SECONDARY METABOLITES IN PLANT DEFENCE

Article ID: AG-VO6-I10-25

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1. Introduction

Plants synthesize thousands of organic compounds through highly coordinated metabolic pathways. These compounds are broadly associated with two major aspects of plant metabolism. Primary metabolites are essential for basic biological processes such as growth, development, energy production and reproduction. In addition to these compounds, plants produce a diverse group of compounds known as secondary or specialized metabolites. These compounds are particularly important in interactions between plants and their environment.

Metabolites are organic compounds synthesized by organisms through enzyme mediated chemical reactions that occur through metabolic pathways. Primary metabolites are generally widespread because they perform fundamental functions required by plant cells. Secondary metabolites, in contrast, are distributed more variably across the plant kingdom and often have functions that are specific to particular plants or ecological situations. Many of them are responsible for colour, fragrance and flavour and participate in interactions with other organisms.

1.1 Importance of Plant Metabolites

Plant metabolites collectively contribute to growth and development, energy production and storage, structural integrity, stress tolerance, defence against biotic stress, antioxidant protection, signalling and regulation, and nutritional value. Thus, metabolism is not restricted to the production of compounds required for cellular growth; it also provides the chemical and structural basis for plant survival and adaptation.

1.2 Primary and Secondary Metabolites

Feature	Primary metabolites	Secondary metabolites
Role	Essential for growth, development and reproduction	Not directly involved in growth, development and reproduction
Distribution	Generally widespread among organisms	Numerous and variably distributed
Production	Associated with growth phase (trophophase)	Associated with non-growth phase (idiophase)
Quantity	Generally produced in larger quantities	Usually accumulated in smaller quantities
Defence	Generally not major defence compounds	Many participate in defence
Examples	Proteins, carbohydrates, lipids, amino acids, nucleic acids	Alkaloids, phenolics, sterols, steroids, essential oils and lignins

2. Structural Metabolites

Structural metabolites are biomolecules that form the physical framework of plant cells and tissues. They provide mechanical strength, rigidity, protection and structural integrity. Unlike compounds whose major roles are chemical defence or signalling, structural metabolites are integrated into the cell wall, cuticle and supporting tissues. Their deposition changes during cell expansion, maturation and vascular development, allowing plants to maintain cell shape and tissue organization while responding to mechanical and environmental stresses.

2.1 General Characteristics

Structural metabolites are indispensable components of plant tissues and are commonly represented by complex polysaccharides or polymers. They are primarily associated with the primary and secondary cell walls, middle lamella and protective outer layers. Their composition determines the balance between rigidity and flexibility. Once deposited, many structural

components remain relatively stable and undergo limited metabolic turnover. They are mainly derived from carbohydrate precursors, while lignin is associated with the phenylpropanoid pathway.

2.2 Cellulose

Cellulose is a linear polysaccharide composed of thousands of β-(1→4)-linked glucose molecules. It occurs in both the primary and secondary cell walls and provides the main tensile framework of the plant cell wall. Cellulose helps maintain cell shape, supports stems and leaves, prevents cell bursting under osmotic pressure and permits controlled cell expansion.

2.3 Hemicellulose

Hemicellulose is a heterogeneous group of branched polysaccharides that includes xylans, mannans, glucomannans and xyloglucans. Cellulose microfibrils provide the principal framework, but they require connecting components. Hemicellulose links cellulose microfibrils, acts as a molecular glue within the wall matrix, provides flexibility, prevents excessive stretching and contributes to cell-wall strength.

2.4 Pectin

Pectin is a complex polysaccharide rich in galacturonic acid. It is mainly associated with the middle lamella and primary cell wall. Pectin cements adjacent plant cells, maintains tissue integrity, facilitates cell adhesion and contributes to regulation of water movement and wall porosity. Its properties also make it important during fruit ripening.

2.5 Lignin

Lignin is a complex aromatic polymer deposited mainly in secondary cell walls. It is particularly abundant in xylem vessels, fibres and sclerenchyma. Lignification increases tissue rigidity, waterproofs xylem and enables long-distance water transport. It also contributes to resistance against pathogens and mechanical damage, allowing plants, particularly trees, to develop strong vascular tissues.

2.6 Cutin and Suberin

Cutin is a polyester composed of hydroxy fatty acids and forms the plant cuticle covering leaves and young stems. It reduces water loss, protects against UV radiation, limits pathogen entry and minimizes mechanical injury. Suberin is a waxy, hydrophobic polymer found in cork cells, the root endodermis and wound tissues. It prevents water loss, acts as a barrier against pathogens, regulates water and ion movement and seals wounds.

2.7 Callose

Callose is a β-(1→3)-glucan polysaccharide. It forms cell plates during cell division, seals damaged sieve tubes, closes plasmodesmata and strengthens cell walls under stress. It is rapidly deposited following wounding and pathogen attack, making it an important component of localized structural defence.

3. Major Structural Metabolites and Their Functions

The different structural metabolites do not perform identical functions. Instead, they form an integrated structural system. Cellulose provides tensile strength, hemicellulose connects cellulose fibres, pectin maintains adhesion between cells, lignin reinforces secondary walls and vascular tissues, while cutin and suberin create hydrophobic barriers. Callose provides rapid localized reinforcement at sites such as wounds, plasmodesmata and sieve plates.

Structural metabolite	Main location	Principal function
Cellulose	Primary and secondary cell wall	Tensile strength; maintenance of cell shape
Hemicellulose	Cell-wall matrix	Cross-linking cellulose; flexibility and strength
Pectin	Middle lamella and primary wall	Cell adhesion, wall porosity and water retention
Lignin	Secondary wall and xylem	Rigidity, waterproofing and pathogen resistance
Cutin	Plant cuticle	Reduced water loss and protection of aerial organs
Suberin	Cork cells and endodermis	Barrier to water, ions and pathogens; wound sealing
Callose	Plasmodesmata, sieve plates and wounds	Tissue sealing and limitation of pathogen spread

3.1 Structural Role in Plant Development and Stress Tolerance

Structural metabolites support plant growth by maintaining cell shape and tissue organization and by changing their deposition as tissues differentiate. During vascular development, lignification provides the rigidity required for water-conducting tissues. Cellulose and hemicellulose provide the framework needed for controlled cell expansion, while pectin

maintains adhesion between neighbouring cells. Protective outer polymers such as cutin and suberin reduce uncontrolled water movement and form barriers at interfaces between the plant and its environment.

These structural components also contribute to stress tolerance. Reinforced walls can reduce mechanical injury and pathogen penetration, hydrophobic barriers can limit water loss, and callose can be rapidly deposited at damaged sites. Structural and protective functions therefore overlap, with physical reinforcement providing the first line of resistance while chemical defence compounds provide additional protection.

4. Protective Metabolites

Protective metabolites are plant-derived compounds that protect plants from biotic and abiotic stresses by acting as physical, chemical or biochemical defence molecules. Most belong to secondary or specialized metabolism. They help plants respond to pathogens, herbivory, drought, salinity, heat, cold, UV radiation and oxidative damage. Some primary metabolites, including osmoprotective compounds, can also contribute to protection, but the presentation emphasizes secondary metabolites as the major group.

4.1 Characteristics of Protective Metabolites

Protective metabolites are mainly defence-oriented, often low-molecular-weight compounds with strong biological activity. They may be constitutively present or induced following stress. Their distribution can be species-specific and they may accumulate in particular tissues such as leaves, bark, seeds, roots, fruits, trichomes and vacuoles. A single metabolite can perform more than one function, including antimicrobial, antioxidant, allelopathic, insecticidal and signalling activities.

5. Major Protective Metabolites

5.1 Alkaloids

Alkaloids are nitrogen-containing secondary metabolites with strong biological activity. They can be toxic to insects and herbivores, inhibit microbial growth, affect insect nervous systems and reduce feeding. Important examples given in the presentation include nicotine in tobacco, caffeine in coffee and tea, morphine in the opium poppy and quinine in Cinchona.

5.2 Phenolic Compounds

Phenolic compounds form a large group of aromatic compounds containing hydroxyl groups. They contribute to antioxidant activity, strengthen cell walls, inhibit pathogen growth,

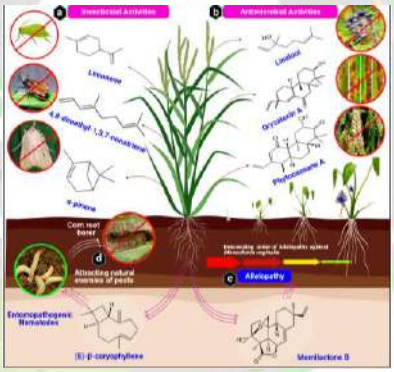
scavenge reactive oxygen species and protect plants against UV radiation. Examples include salicylic acid, tannins, gallic acid and ferulic acid.

5.3 Flavonoids

Flavonoids are polyphenolic pigments synthesized through the phenylpropanoid pathway. Their functions include antioxidant activity, UV protection and antimicrobial activity. They can also attract beneficial pollinators and function as signalling molecules in legume–Rhizobium interactions. Quercetin, kaempferol, anthocyanins and catechins are examples.

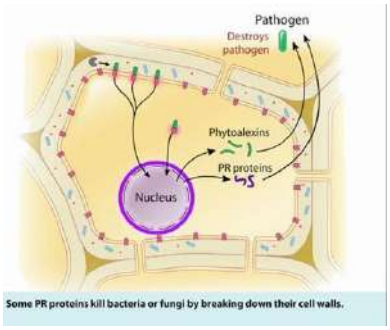
5.4 Terpenoids

Terpenoids constitute the largest class of plant secondary metabolites and are derived from isoprene units. They can repel insects, attract predators of herbivores and provide antifungal and antibacterial activity. They also contribute to protection against heat and oxidative stress. Examples include menthol from mint, limonene from citrus peel, artemisinin from sweet wormwood and pyrethrins from pyrethrum daisy.



5.5 Phytoalexins

Phytoalexins are antimicrobial compounds synthesized following pathogen attack. They help kill or inhibit fungi and bacteria, restrict pathogen spread and strengthen localized defence. Examples include resveratrol in grape, camalexin in Arabidopsis, pisatin in pea and phaseollin in bean.

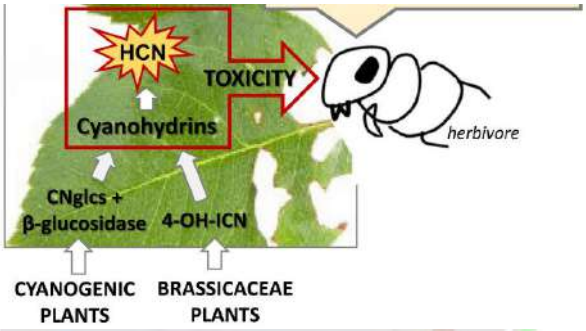


5.6 Tannins

Tannins are polyphenolic compounds capable of binding proteins. By interacting with proteins and digestive enzymes, they reduce the digestibility of plant tissues and discourage herbivore feeding. They also show antimicrobial activity. The two major groups identified in the presentation are hydrolysable tannins and condensed tannins.

5.7 Cyanogenic Glycosides

Cyanogenic glycosides are compounds that can release hydrogen cyanide (HCN) when plant tissues are damaged. The released HCN makes damaged tissues toxic to herbivores and can disturb insect feeding and reduce pathogen survival. Examples include linamarin in cassava, dhurrin in sorghum and amygdalin in bitter almond.



5.8 Summary of Protective Metabolites

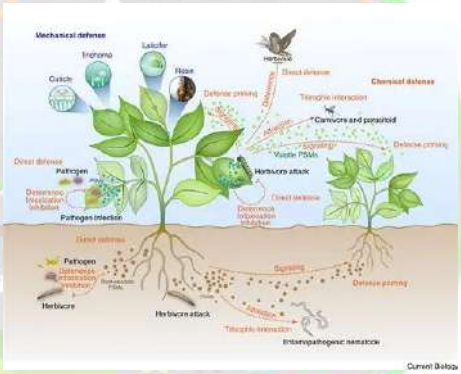
Class	Examples	Major function
Phenolics	Phenolic acids, lignin	Antimicrobial activity, antioxidant defence and wall reinforcement
Flavonoids	Quercetin, kaempferol, anthocyanins	ROS scavenging, UV protection and signalling
Terpenoids	Menthol, limonene, carotenoids	Herbivore deterrence, volatile signalling and antioxidant activity
Alkaloids	Nicotine, caffeine, quinine, morphine	Toxicity against insects and herbivores
Tannins	Hydrolysable and condensed tannins	Protein precipitation and feeding deterrence
Glucosinolates	Sinigrin	Defence against insects and pathogens
Phytoalexins	Resveratrol, camalexin	Antimicrobial response after infection
Cyanogenic glycosides	Amygdalin, dhurrin	HCN release and herbivore deterrence

6. Secondary Metabolites in Plant Defence

Plants are sessile organisms and cannot escape pathogens, herbivores or environmental stresses. Consequently, they have evolved sophisticated defence systems based on secondary metabolites. When plants perceive stress signals, defence signalling pathways activate the biosynthesis and accumulation of specialized metabolites. These compounds may inhibit pathogen growth, deter herbivores, strengthen structural barriers and regulate defence-related gene expression.

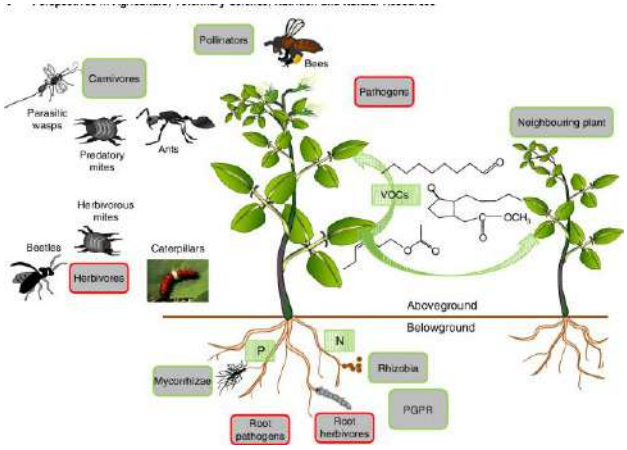
6.1 Direct Chemical Defence

In direct chemical defence, secondary metabolites act directly against pathogens or herbivores. They may be toxic, inhibit fungal and bacterial growth, reduce insect feeding or interfere with digestive enzymes. Nicotine, capsaicin and resveratrol are examples presented as compounds involved in direct chemical defence.



6.2 Indirect Ecological Defence

Secondary metabolites can also protect plants indirectly by changing ecological interactions. After herbivore attack, plants may release volatile organic compounds that attract parasitoids or predators of the herbivores.



These volatile signals can also function in communication and may warn neighbouring plants. Methyl jasmonate, monoterpenes and sesquiterpenes are examples associated with indirect defence.

6.3 Structural Defence

Secondary and specialized metabolites can contribute to structural defence by reinforcing the plant cell wall and reducing pathogen penetration. Lignin, suberin and callose strengthen or seal tissues and are particularly important after damage or infection. This mechanism complements direct chemical defence by providing a physical barrier.

6.4 Defence Signalling

Secondary metabolites participate in signalling pathways that coordinate plant defence. Jasmonic acid (JA), salicylic acid (SA), WRKY transcription factors and the MAP kinase cascade are important components identified in the presentation. Therefore, secondary metabolites are not simply toxic compounds; they also regulate the timing and intensity of plant responses.

6.5 Defence Against Pathogens

Pathogens can enter plant tissues through natural openings or wounds. Plants respond through recognition of pathogen-associated signals followed by activation of defence pathways. Secondary metabolites can disrupt cell membranes and cell walls, inhibit enzymes and protein synthesis, damage DNA and suppress virulence-related processes. Phytoalexins are especially important because they are rapidly synthesized after infection and help restrict pathogen growth.

Compound	**Defence function**
Phytoalexins	Induced antimicrobial compounds
Phenolics	Cell-wall strengthening
Flavonoids	Antifungal activity
Lignin	Physical barrier
Tannins	Protein precipitation
Coumarins	Antibacterial activity

6.6 Defence Against Herbivores

Plants produce toxic and deterrent metabolites that reduce herbivore feeding and survival. The presentation identifies neurotoxicity, reduced digestion, feeding deterrence, inhibition of oviposition and reduced insect growth as major modes of action.

Compound	Plant	Function
Nicotine	Tobacco	Neurotoxin
Caffeine	Coffee	Feeding deterrent
Capsaicin	Chilli	Mammalian deterrent
Pyrethrin	Chrysanthemum	Natural insecticide
Glucosinolates	Brassica	Toxic isothiocyanates

7. Secondary Metabolites in Antioxidant Defence

Oxidative stress occurs when the production of reactive oxygen species (ROS) exceeds the antioxidant capacity of the plant. Secondary metabolites provide an important non-enzymatic antioxidant defence system. They can neutralize reactive molecules before irreversible cellular damage occurs and thereby contribute to plant survival under stress.

7.1 Mechanisms of Antioxidant Action

Antioxidant secondary metabolites can directly scavenge free radicals and donate electrons or hydrogen atoms. They can also chelate transition metals such as Fe^{2+} and Cu^{2+}, prevent lipid peroxidation and stabilize cellular membranes. Phenolics and flavonoids are highlighted as particularly effective plant-derived antioxidants because they can donate electrons and stabilize free radicals.

Metabolite	Major antioxidant role
Flavonoids	ROS scavenging
Phenolic acids	Hydrogen donation
Anthocyanins	Photoprotection
Carotenoids	Quenching singlet oxygen
Tannins	Metal chelation and free-radical scavenging

8. Hormonal Regulation of Secondary Metabolites

Secondary metabolite production is regulated by plant hormones that coordinate defence responses. Jasmonic acid is associated with insect attack, wounding and necrotrophic pathogens and stimulates the production of alkaloids, terpenoids and volatile organic compounds. Salicylic acid is associated with biotrophic pathogens and stimulates phenolics, pathogenesis-related proteins, flavonoids and phytoalexins. Transcription factors such as WRKY, MYB, MYC2 and

ERF participate in regulating the expression of defence-related genes.

Jasmonic acid is synthesized from the membrane fatty acid α-linolenic acid. Following tissue damage or herbivore attack, lipoxygenase initiates the pathway and produces oxylipin intermediates that ultimately lead to OPDA and jasmonic acid. Jasmonic acid can be conjugated with isoleucine to form JA-Ile, an important bioactive signal.

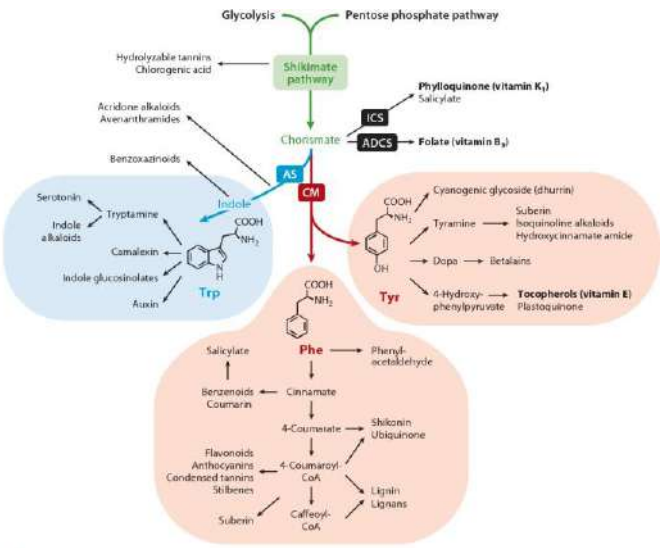
9. Biosynthetic Pathways of Secondary Metabolites

Secondary metabolites are synthesized from primary metabolic precursors through specialized biosynthetic pathways. The presentation identifies the shikimate pathway, phenylpropanoid pathway, mevalonate pathway, MEP pathway and alkaloid pathways as major routes contributing to the diversity of secondary metabolites.

Biosynthetic pathway	Major precursor	Major products
Shikimate	PEP + erythrose-4-phosphate	Aromatic amino acids, phenolics, flavonoids, tannins and lignin
Phenylpropanoid	Phenylalanine	Phenolics, flavonoids, lignin, coumarins and phytoalexins
Mevalonate (MVA)	Acetyl-CoA	Sesquiterpenes, triterpenes and sterols
MEP (DOXP)	Pyruvate + glyceraldehyde-3-phosphate	Monoterpenes, diterpenes and carotenoids
Alkaloid pathway	Tyrosine, tryptophan, lysine and ornithine	Alkaloids

9.1 Shikimate and Phenylpropanoid Pathways

The shikimate pathway connects primary carbohydrate metabolism with the production of aromatic amino acids, particularly phenylalanine, tyrosine and tryptophan. These amino acids subsequently serve as precursors for many secondary metabolites. The phenylpropanoid pathway uses phenylalanine as a major precursor and contributes to the biosynthesis of phenolics, flavonoids, lignin, coumarins and phytoalexins.



Conclusion

Secondary metabolites represent a major component of plant specialized metabolism and are essential for plant interaction with the environment. Structural metabolites maintain the physical organization and strength of plant tissues, whereas protective metabolites provide chemical and biochemical defence. Their functions include pathogen inhibition, herbivore deterrence, antioxidant protection, structural reinforcement and signalling. Hormones such as jasmonic acid and salicylic acid coordinate their production, while specialized biosynthetic pathways convert primary metabolic precursors into diverse protective compounds. Together, structural and protective metabolites provide complementary mechanisms that enhance plant survival, defence and adaptation.

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Volume: 06 Issue No: 10

SEED PRIMING FOR BETTER PRODUCTION IN PLANTS

Article ID: AG-VO6-I10-26

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Introduction

Seed priming is a controlled pre-sowing treatment in which seeds are partially hydrated under controlled conditions to initiate the early physiological processes of germination, but the radicle is not allowed to emerge. The seeds are then dried back to a suitable moisture level before sowing. In simple words, seed priming prepares the seed for faster and more uniform germination and better seedling establishment.

Methods of Seed Priming

The main methods are:

1. **Hydropriming**
    - Seeds are soaked in water for a specified period and then dried.
    - Simple, inexpensive and suitable for small-scale farming.
2. **Osmopriming**
    - Seeds are soaked in an osmotic solution such as PEG (polyethylene glycol) or certain salts.
    - Water enters the seed slowly and uniformly.
3. **Halopriming**
    - Seeds are treated with dilute solutions of inorganic salts such as KNO_3, KCl, $CaCl_2$ or NaCl.
    - Can improve germination and seedling vigour under stress.
4. **Hormonal/chemical priming**
    - Seeds are treated with plant growth regulators or beneficial chemicals such as

- GA_3, salicylic acid, ascorbic acid, etc.
- Used to improve germination, vigour and stress tolerance.

5. **Biopriming**
   - Seeds are treated with beneficial microorganisms such as Trichoderma or selected plant-growth-promoting bacteria.
   - Helps improve seedling establishment and may suppress seed-borne/soil-borne pathogens.
6. **Nutrient priming**
   - Seeds are treated with solutions containing nutrients or micronutrients such as Zn, Fe, Mn or B, depending on crop requirement.
7. **Solid-matrix priming**
   - Seeds are mixed with a moist solid carrier such as vermiculite, sand or other suitable materials.
   - Provides slow and controlled hydration.

Types of Seed Priming

Type	Main treatment	Major purpose
Hydropriming	Water	Faster, uniform germination
Osmopriming	PEG/osmotic solution	Controlled hydration
Halopriming	Salt solution	Vigour and stress tolerance
Hormonal priming	GA_3, SA, etc.	Germination and growth
Biopriming	Beneficial microbes	Disease protection and vigour
Nutrient priming	Mineral nutrients	Better nutrient availability
Solid-matrix priming	Moist solid carrier	Controlled water uptake

What is Seed Priming Used For

Seed priming is mainly used for:

i. Increasing germination percentage
ii. Reducing time required for germination
iii. Obtaining uniform germination
iv. Improving seedling vigour
v. Improving root and shoot development

vi. Improving crop establishment
vii. Increasing emergence under difficult conditions
viii. Improving tolerance to drought, salinity, temperature and other stresses
ix. Improving early nutrient uptake
x. Reducing problems associated with slow and uneven emergence
xi. Improving the effectiveness of some biological seed treatments
xii. In some crops, improving yield and yield components

Importance of Seed Priming: Seed priming is particularly important in dryland and arid/semi-arid agriculture, where soil moisture may be limited and rapid establishment is essential.

Major benefits

1. Faster germination:

Primed seeds generally germinate more rapidly because important metabolic processes have already been initiated.

2. Uniform emergence:

Plants emerge more uniformly, resulting in a more even crop stand.

3. Better seedling vigour:

Priming can improve early root and shoot growth.

4. Better crop establishment:

Rapid establishment helps seedlings utilize available soil moisture more effectively.

5. Stress tolerance:

Appropriate priming treatments can improve plant responses to drought, salinity, temperature and other environmental stresses.

6. Better stand establishment under marginal conditions:

This is particularly useful in rain fed areas where the sowing window and soil moisture may be limited.

7. Improved resource-use efficiency:

A uniform crop stand can improve the utilization of water, nutrients, light and space.

Role of Seed Priming in National Economy: Seed priming can contribute to the national economy through several pathways:

1. Increased crop productivity

Better germination and establishment can contribute to higher and more stable crop yields.

2. Reduction in re-sowing

Poor germination sometimes requires re-sowing. Priming can reduce uneven emergence and thereby reduce expenditure on seed, labour and field preparation.

3. Efficient use of seed

Uniform establishment allows farmers to make better use of purchased seed.

4. Improved production in dry areas

In rainfed and arid/semi-arid regions, rapid establishment is particularly valuable because available moisture may be short-lived.

5. Improved food security

Higher and more stable agricultural production supports national food and nutritional security.

6. Higher farm income

Improved establishment and productivity can increase the economic returns of farmers when the priming treatment is properly selected and economically justified.

7. Employment and seed-treatment industry

Commercial seed-treatment, microbial inoculant and agricultural-input industries generate economic activity and employment.

8. Climate-resilient agriculture

Priming can be one component of low-cost strategies for improving crop establishment under environmental stress, potentially reducing production risks.

Merits/Advantages of Seed Priming

i. Simple technique for many crops.
ii. Can produce faster and more uniform germination.
iii. Improves seedling vigour.
iv. Can improve crop establishment.
v. May improve tolerance to drought and salinity.
vi. Can be relatively inexpensive, especially hydropriming.
vii. May reduce the need for re-sowing.
viii. Can improve early root development.
ix. Can increase uniformity of crop growth.
x. Some priming methods can improve resistance to seedling diseases.
xi. Useful for both irrigated and rainfed agriculture.

xii. Particularly valuable for stress-prone environments.

Demerits/Limitations of Seed Priming

i. Incorrect soaking duration can damage seeds or reduce viability.
ii. Excessive moisture can cause premature germination.
iii. Primed seeds may have shorter storage life in some circumstances, particularly if drying and storage are not properly managed.
iv. Requires proper control of time, temperature, moisture and treatment concentration.
v. Different crops and varieties require different priming conditions.
vi. Excessive salt or chemical concentration can become toxic.
vii. Biopriming requires appropriate microorganisms and hygienic handling.
viii. Priming, drying and handling add labour and management requirements.
ix. Poorly dried primed seeds may deteriorate or develop storage problems.
x. Benefits are not always consistent under every soil, climate and crop condition.
xi. Commercial priming treatments can increase seed-treatment costs.

Summary: Seed priming → controlled hydration/treatment → activation of physiological processes → faster germination → uniform emergence → vigorous seedlings → better crop establishment → potentially higher and more stable productivity. Seed priming is an important pre-sowing seed-management technique used to improve germination, seedling vigour, crop establishment and stress tolerance, thereby contributing to more efficient and productive agriculture.

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: 10

SMALL HIVE BEETLE IN APIARIES: AN EMERGING THREAT TO HONEY BEE COLONIES AND ITS MANAGEMENT

Article ID: AG-VO6-I10-27

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Introduction

The small hive beetle, *Aethina tumida* Murray (Coleoptera: Nitidulidae), is an invasive and increasingly important pest of managed honey bee colonies. It is capable of damaging brood, pollen, honey stores and wax combs, while also causing fermentation and spoilage of honey. In severe cases, the pest can lead to the collapse or absconding of colonies and substantial losses of marketable honey and comb. The recent detection of small hive beetle in different regions of India, including reports from Tamil Nadu, has raised concern among beekeepers, researchers and apiculture-development agencies. The pest is especially important in warm and humid

environments, where its multiplication is rapid and where weak colonies or poorly managed honey supers provide ideal conditions for infestation.

Origin and Importance of the Pest

Small hive beetle is native to sub-Saharan Africa, where African honey bees have evolved behavioural and defensive mechanisms that often keep its population under control. However, when the beetle enters new areas, it can become a destructive invasive pest because local honey bee colonies may not sufficiently restrict its reproduction. The pest has spread to several honey bee-producing countries through movement of bee colonies, queens, package bees, used hive equipment, combs and hive products.



Fig. 1 Small hive beetle larvae damaging honey comb; severe larval feeding results in leakage and spoilage of honey.

The principal host of the pest is the western honey bee, *Apis mellifera*, particularly colonies maintained for honey production and pollination. However, small hive beetle can survive in colonies of other honey bee species and can reproduce in abandoned colonies, unprotected combs, honey houses and stores of pollen-rich materials. Recent surveillance in Tamil Nadu has highlighted the potential risk to *A. mellifera*, *Apis cerana indica* and unmanaged or abandoned honey bee colonies. Such a situation makes it necessary to consider small hive beetle as an apiary-level and landscape-level pest rather than merely a problem of individual hives.

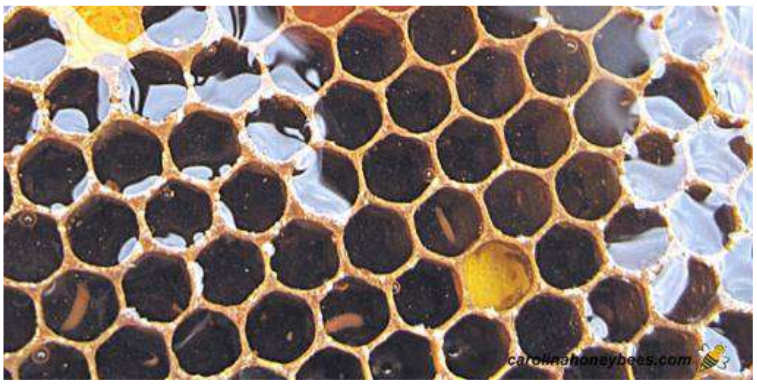


Fig. 2 Larval infestation of comb may cause wet, slimy and fermented honey conditions inside the hive..

The economic importance of small hive beetle lies not only in direct feeding by larvae but also in the contamination of hive products. Larvae feed on pollen, brood, honey and wax comb, creating tunnels through cells and causing honey to leak. Their feeding activity and excreta induce fermentation of honey, resulting in frothing, sour odour, discolouration and a slimy appearance of combs. Once honey becomes fermented and contaminated, it loses commercial value and cannot be used for human consumption.

Recognition of Small Hive Beetle

Early identification is essential for minimizing losses. Adult small hive beetles are small, flattened and oval-shaped insects, generally measuring about 5–7 mm in length. Freshly emerged adults may appear reddish-brown, but they soon become dark brown to black. They are fast-moving and avoid light, quickly hiding in narrow spaces within the hive. They are commonly found under the top cover, between frame lugs, in the corners of hive boxes, beneath the bottom board, under debris and inside cracks containing propolis.



Fig. 3 Heavy infestation of small hive beetle larvae in comb, a typical precursor to sliming and honey fermentation

One important field character is the short wing cover of the adult beetle. The hardened forewings do not completely cover the abdomen, making the terminal portion of the abdomen visible. This feature helps distinguish the pest from several other small beetles that may occasionally occur in bee colonies. During hive inspection, adult beetles often run rapidly over the comb surface and seek refuge in concealed areas as soon as frames are exposed to light.

The larval stage is responsible for the most serious damage. Small hive beetle larvae are creamy white, elongated and segmented, with three pairs of well-developed legs near the head. They possess rows of small spines along the back, which make the body appear rough. Beekeepers may confuse them with wax moth larvae, but wax moth larvae generally produce prominent webbing in the comb, whereas small hive beetle larvae are more commonly associated with slimy, wet and fermenting combs. The presence of large numbers of active larvae crawling over honey and pollen combs is a clear indication of a serious infestation.

Life Cycle of the Beetle

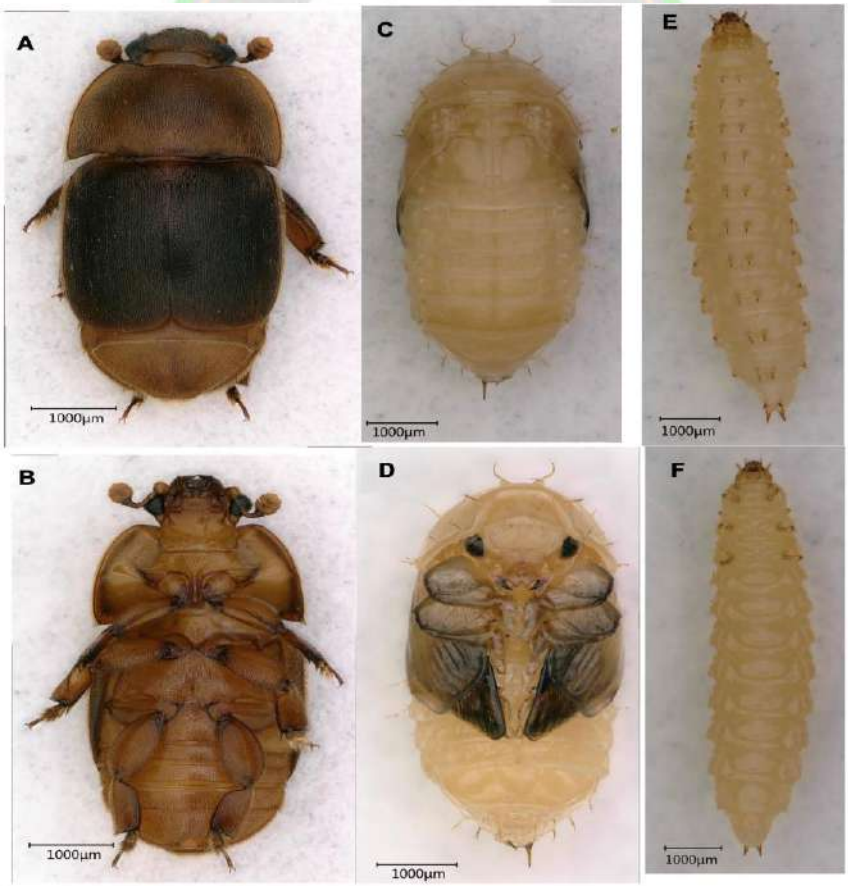


Fig 4. Life Stages of small hive beetles (Atheina tumida), showing adult, pupa and larva forms

Life stages of small hive beetles (*Aethina tumida*), showing adult, pupa, and larva forms.

The life cycle of small hive beetle includes egg, larval, pupal and adult stages. Females lay eggs in protected areas inside the colony, particularly in cracks, crevices, pollen cells, brood cells and other spaces that are difficult for worker bees to reach. Eggs are very small, whitish and usually difficult to detect during routine examination of colonies. Under favourable warm conditions, eggs may hatch within 24–48 hours.

The newly hatched larvae feed actively on pollen, brood, honey and wax residues. The feeding larval period may last about four to five days, after which the mature larvae become wandering larvae. These mature larvae leave the hive in search of soil, often moving down through the hive entrance or other gaps. They then burrow into soil around the hive and pupate. The pupal period may range from about 13 to 25 days depending on soil temperature, moisture and other environmental conditions. Adult beetles emerge from soil and return to bee colonies, where they feed, mate and begin another generation.

Under warm conditions, the entire life cycle may be completed in approximately 23 days, allowing rapid population increase. Lower temperatures may delay development, but warm and humid conditions promote faster multiplication. This short life cycle explains why a colony with a few unnoticed beetles can develop into a severe infestation within a relatively short time.

Damage Caused in Bee Colonies

Small hive beetle adults and larvae cause different types of injury. Adult beetles invade colonies and seek hiding places, while larvae feed extensively on hive resources. Larvae consume pollen, honey and brood, and their movement through combs damages wax cells. The greatest losses occur when larvae infest honey supers or stored combs. Honey leaks from damaged cells, becomes contaminated with larval excreta and begins to ferment.

The fermented honey often gives off a sour, unpleasant smell and may appear frothy or bubbly. Combs become wet, darkened and covered with a slimy material. This condition is popularly called a “slime-out.” In a severe slime-out, frames, honey supers and hive boxes may become unusable. Worker bees may abandon the affected combs, become stressed or abscond completely from the colony. Weak colonies are especially likely to collapse when small hive beetle larvae multiply rapidly.

The pest is also a serious problem in honey extraction facilities. Honey supers removed from hives and kept for long periods before extraction are vulnerable to beetle egg hatch and

larval development. Even combs that appear healthy at the time of removal may become severely infested if stored in warm conditions for several days. Therefore, poor post-harvest handling can cause losses even when colonies in the apiary appear adequately managed.

Conditions Favouring Infestation

Small hive beetle is an opportunistic pest that flourishes when bee colonies are weak or when hive management creates unprotected areas. Colonies weakened by queen failure, disease, starvation, pesticide stress, lack of forage, excessive division or poor bee population are less able to control beetles. Strong colonies can often chase, confine or restrict adult beetles in narrow spaces, but weak colonies cannot patrol all combs effectively.

Excess hive space also favours infestation. When beekeepers add supers prematurely or retain too many empty combs, adult beetles find protected spaces for hiding and egg laying. Frames that are not covered by worker bees become particularly vulnerable. Similarly, unused pollen supplements, pollen patties and protein feeds may attract beetles and support larval multiplication if they are left in the hive for long periods.

Apiary conditions also influence the pest. Moist, shaded and loose soil may favour the survival and pupation of wandering larvae. Accumulated wax debris, spilled honey, burr comb, abandoned hives, dead colonies and poorly stored combs can act as reservoirs. Apiaries and honey houses that are not regularly cleaned may therefore support continuous pest multiplication and reinfestation.

Detection and Monitoring

Regular monitoring is the most reliable way to avoid severe damage. Colonies in areas where small hive beetle is suspected or confirmed should be inspected at intervals of about 7–10 days. Beekeepers should carefully examine hive corners, bottom boards, frame rests, inner covers, pollen combs and brood combs. Adult beetles may be seen running rapidly away from light, while larvae may be observed on combs or in hive debris.

The earliest visible warning sign is usually the presence of a few dark adult beetles in concealed parts of the hive. A more serious warning is the occurrence of larvae in pollen or honey combs. When slime, fermented odour, leaking honey and large numbers of larvae are seen, immediate action is required. Beekeepers should maintain records of colony strength, queen status, visible beetle numbers, trap catches and corrective actions. Such records help identify high-risk colonies and seasonal patterns of infestation.

Maintaining Strong Colonies

Maintaining strong, queen-right colonies is the most important foundation for managing small hive beetle. Colonies should have adequate worker bee populations to cover brood, food stores and comb surfaces. Queenless colonies should be requeened without delay, and chronically weak colonies should be united with stronger colonies when appropriate. Colonies should not be divided excessively during periods of poor forage availability or when pest pressure is high.

Beekeepers should avoid giving too much empty space to colonies. Honey supers should be added only when the existing brood and comb space is well occupied by bees. Unused combs should not be retained in weak colonies, and frames that are not adequately protected by worker bees should be removed. These simple measures reduce the hiding places available to adult beetles and limit opportunities for larval development.

Sanitation and Honey-House Hygiene

Apiary sanitation is one of the most effective non-chemical methods for suppressing small hive beetle. Dead colonies, abandoned boxes, discarded combs and heavily infested frames should not be left exposed in or near the apiary. Such material can become breeding sites and may produce large numbers of adult beetles capable of reinfesting nearby colonies.

Honey supers should be extracted as quickly as possible after removal from the hive, preferably within 48 hours. Delayed extraction gives beetle eggs time to hatch and allows larvae to feed on honey and pollen residues in the comb. Honey rooms should be clean, dry and protected from beetle entry. Spilled honey, wax scrapings, pollen residues and comb waste should be removed immediately.

Stored brood combs and pollen combs require special attention because they are highly attractive to small hive beetle larvae. Where suitable, combs intended for storage can be frozen before reuse to kill eggs, larvae and adults. Combs that are heavily slimed, fermented or structurally damaged should be destroyed safely according to local recommendations and should never be left uncovered in the apiary.

Traps and Physical Methods

Traps are useful tools for monitoring and reducing adult beetle populations. Several types of traps are available, including bottom-board oil traps, in-hive beetle traps, corrugated plastic traps, frame-top traps and larval interception traps. Adult beetles are attracted to dark, narrow

spaces, and many traps use this behaviour to capture them. Oil-based traps can drown beetles that enter the device, whereas certain other designs retain beetles in restricted spaces for later removal.

Larval traps are also important because mature larvae must leave the hive to pupate in soil. Devices designed to intercept wandering larvae before they enter the soil can reduce the number of future adults emerging around the apiary. Traps should be inspected, cleaned and maintained regularly. A neglected trap may lose effectiveness, become clogged with debris or provide misleading information about beetle activity.



Fig. 4 Bottom-board oil trap used to capture adult small hive beetles in managed honey bee colonies

Soil-Phase Management

The soil surrounding bee colonies plays a major role in the life cycle of small hive beetle. Mature larvae leave the hive and burrow into nearby soil to pupate. Consequently, managing the soil phase can reduce the emergence of new adults. Apiaries should be kept free from debris, spilled honey, abandoned equipment and infested comb material that can attract larvae.

Where possible, apiaries should avoid persistently wet and shaded sites with loose soil that may be favourable for beetle pupation. Physical barriers and larval interception systems can

be useful in preventing wandering larvae from reaching soil. Biological control using entomopathogenic nematodes such as *Steinernema riobrave* and *Heterorhabditis indica* has also shown potential for suppressing soil-dwelling stages of small hive beetle. These biological options are particularly relevant for sustainable IPM programmes because they target the pest outside the bee colony.

Chemical Management and Caution

Chemical control should be considered only when necessary and only under the guidance of authorized agencies. Some products used in other countries include coumaphos-based in-hive treatments and soil treatments with certain insecticides. However, registration, recommended dose, residue limits, efficacy and safety differ among countries and regions.

Beekeepers should never use unlabelled insecticides, household sprays or unauthorised chemicals within bee colonies. Such practices can contaminate honey, wax, pollen and bee feed, injure honey bees, create residue problems and reduce the safety of hive products. In the Indian context, the preferred approach is to follow recommendations issued by agricultural universities, state apiculture departments and other competent authorities. Strong colonies, sanitation, fast honey extraction and trapping should remain the central components of management.

Managing a Severe Infestation

When a colony develops a severe slime-out, quick action is needed to prevent spread. Infested combs should not be transferred to healthy colonies. Slimed combs containing large numbers of larvae should be removed from the apiary and destroyed safely. Lightly infested combs that can still be salvaged may be frozen before reuse. Hive boxes, bottom boards, covers and associated equipment should be cleaned thoroughly.

The colony should then be assessed for queen status and worker population. If the remaining colony is very weak, it may be better to unite it with a stronger colony after careful examination and appropriate local advice. Nearby colonies should be inspected more frequently because adult beetles may already have dispersed within the apiary. It is important to stop mature larvae from reaching soil, as pupation in the soil will lead to the emergence of a fresh generation of adult beetles.

Importance for Tamil Nadu Beekeeping

The emergence of small hive beetle in Tamil Nadu, particularly the reported detection in the Anamalai region of Pollachi in Coimbatore district, requires organized surveillance and

beekeeper awareness. The reported occurrence in colonies of *A. mellifera*, *A. cerana indica* and abandoned *A. dorsata* colonies indicates that the pest may persist in multiple host environments and could move through apiaries if not detected early.

Beekeepers should avoid moving colonies, used combs, hive boxes and queens from suspected infested areas without proper inspection. Migratory beekeepers require special vigilance because movement of hives can unintentionally spread the pest between districts and states. Training programmes should focus on recognizing adult beetles and larvae, distinguishing larvae from wax moth, maintaining strong colonies, using traps and following hygienic honey-processing practices.

Small hive beetle management is ultimately a matter of preparedness. The pest becomes most destructive when it is ignored until larvae slime the combs. Through regular monitoring, strong colony maintenance, clean apiaries, rapid extraction of honey, protected storage of combs and timely reporting of suspected infestations, beekeepers can greatly reduce colony losses and safeguard honey production.

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Volume: 06 Issue No: 10

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

Article ID: AG-VO6-I10-28

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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.

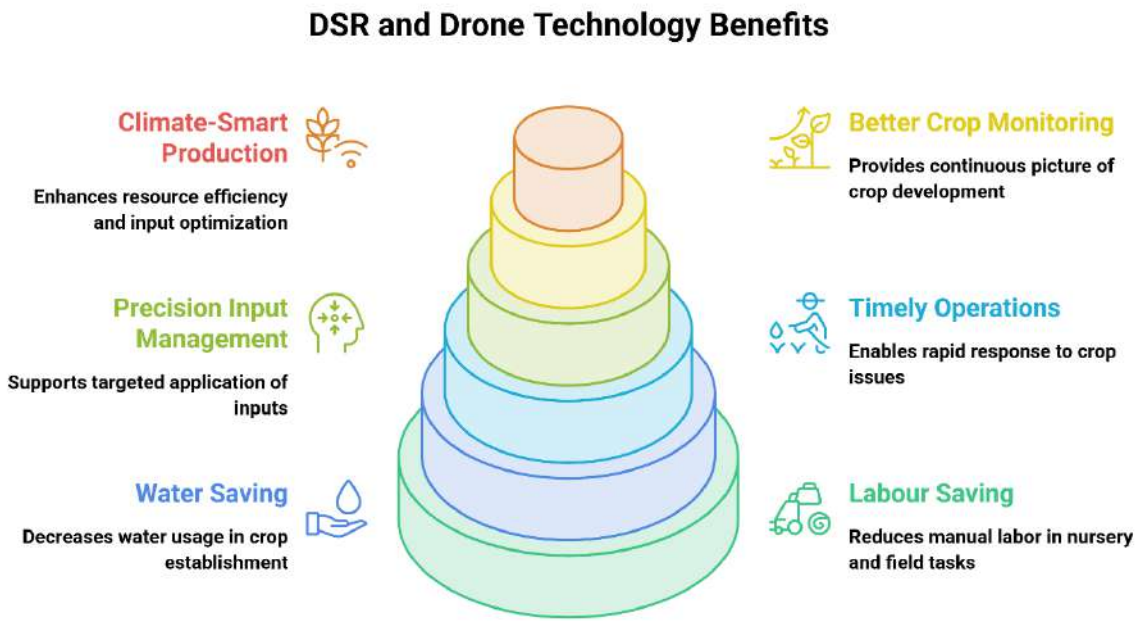


Figure 1. The benefits of integration of drone technology on direct seeded rice

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.

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Volume: 06 Issue No: 10

UNDERWATER PHOTOGRAMMETRY: ADVANCING FISHERIES SCIENCE THROUGH ROV AND AUV TECHNOLOGIES

Article ID: AG-VO6-I10-29

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Abstract

The underwater environment is challenging to study due to limited visibility, variable illumination, depth and restricted human access. Recent advances in underwater imaging, ROVs, AUVs, sonar and computational image processing have enabled non-destructive approaches to marine surveys. Underwater photogrammetry allows three-dimensional reconstruction of habitats and organisms from overlapping images, supporting habitat mapping, fish size and abundance estimation, biomass assessment and biodiversity monitoring (Pulido Mantas et al., 2023; Remmers et al., 2024; Paterson et al., 2024). However, factors such as turbidity, light attenuation, refraction, navigation uncertainty and image quality can affect measurement accuracy (Marre et al., 2019; Remmers et al., 2024). Integrating photogrammetry with ROVs, AUVs, acoustic sensors and artificial intelligence offers promising opportunities for improving fisheries-independent surveys and strengthening sustainable marine resource management.

Introduction

The oceans cover about 71% of the Earth's surface, but their underwater environments remain difficult to study because of depth, limited visibility and complex habitats. Understanding fish populations and their habitats is essential for effective fisheries management, biodiversity conservation and ecosystem-based management. Traditional fisheries surveys use fishing gears, acoustic methods and underwater observations to assess species composition, abundance and biological characteristics. However, trawling can be difficult in rocky, reef-associated and structurally complex habitats and may disturb benthic environments. Therefore, non-destructive approaches are increasingly important for fisheries-independent surveys. Underwater imaging

provides an alternative by allowing marine organisms and habitats to be observed in situ. Underwater photogrammetry further converts overlapping photographs into measurable three-dimensional models, providing information on habitat structure, organism size and spatial relationships (Pulido Mantas et al., 2023). Modern Structure-from-Motion (SfM) techniques can automatically identify common features among overlapping images and reconstruct three-dimensional environments. Advances in digital cameras, image-processing software and computing have expanded its applications to coral reefs, seagrass beds, rocky habitats and artificial reefs (Marre et al., 2019; Remmers et al., 2024). The integration of photogrammetry with remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) further enables systematic surveys of deep, complex and inaccessible marine habitats, providing valuable information for fisheries research and marine ecosystem monitoring.

Understanding Underwater Photogrammetry

Basic principle

The principle of underwater photogrammetry is relatively straightforward. A camera captures a sequence of overlapping photographs of an object or area from different positions. Common features visible in several photographs are identified computationally. Their relative positions, together with camera geometry, are then used to reconstruct the three-dimensional structure of the surveyed environment.

A typical underwater photogrammetric workflow consists of four major stages:

1. **Survey planning and image acquisition**
2. **Image alignment and processing**
3. **Three-dimensional reconstruction**
4. **Measurement and ecological interpretation**

During image acquisition, sufficient overlap between consecutive photographs is required. The images are then processed using photogrammetric software to identify common features and estimate camera positions. A sparse point cloud is initially generated, followed by a dense point cloud and, where required, a three-dimensional surface mesh and textured model. Measurements can subsequently be extracted from the reconstructed model. Photogrammetry therefore converts a collection of two-dimensional photographs into a spatially measurable three-dimensional dataset. This represents a major advantage for marine ecological studies because researchers can

obtain measurements of length, area, volume, surface complexity and spatial relationships without physically collecting the objects (Marre et al., 2019).

Challenges of Underwater Photogrammetry

Underwater photogrammetry faces several technical challenges. Water absorption and light scattering reduce image quality, particularly with increasing depth and turbidity, while suspended particles can cause backscatter and affect image contrast. Refraction at the water–housing–lens interface can also influence image geometry. Therefore, careful camera calibration, image acquisition and quality control are essential for accurate measurements (Pulido Mantas et al., 2023; Remmers et al., 2024). Water movement and strong currents may further affect camera stability, image overlap and sharpness. Proper control of survey speed, camera distance, lighting and environmental conditions is consequently important for obtaining reliable three-dimensional reconstructions.

Platforms Used for Underwater Photogrammetry

Underwater photogrammetric surveys can be conducted using diver-held cameras, remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs). Each platform offers different capabilities depending on survey depth, area and objectives.

Diver-Based Photogrammetry

Divers can capture overlapping images of reefs, organisms and habitats from different viewpoints. This approach provides high flexibility and detailed observations but is limited by dive duration, depth, safety and human endurance. It is therefore particularly suitable for small-scale and detailed surveys.

Remotely Operated Vehicles

A remotely operated vehicle (ROV) is a tethered underwater platform that receives communication and, in many systems, power from a surface vessel. ROVs can carry cameras, lights, sonar and other sensors, allowing detailed observations of deep and inaccessible habitats. Real-time operator control enables precise positioning and imaging of complex structures. Paterson et al. (2024) demonstrated the use of ROV-based photogrammetry for high-resolution reconstruction of maerl bed ecosystems.

Autonomous Underwater Vehicles

An autonomous underwater vehicle (AUV) is an untethered platform capable of conducting pre-programmed underwater surveys. Equipped with cameras, sonar and

environmental sensors, AUVs are suitable for large-area mapping, deep-water surveys, repeated transects and long-term monitoring. Smale et al. (2012) demonstrated the application of AUVs for regional-scale benthic monitoring and ecosystem-based fisheries management. AUV-based surveys can generate large volumes of geo-referenced imagery and provide an alternative for studying complex or untrawlable habitats.

ROV and AUV: Complementary Technologies

ROVs and AUVs should not be considered competing technologies. Rather, they provide complementary capabilities.

Feature	ROV	AUV
Control	Remotely operated	Autonomous
Surface connection	Tethered	Untethered
Communication	Continuous	Limited underwater communication
Power	Often supplied through tether	Onboard battery
Operator control	High	Limited during mission
Survey coverage	Generally localized	Potentially extensive
Major strength	Detailed inspection	Systematic large-area survey
Main limitation	Tether and support vessel	Battery and navigation

Applications in Fisheries Science

Habitat mapping:

Underwater photogrammetry creates detailed 3D models of reefs, rocky habitats, seagrass beds and artificial reefs. It allows researchers to quantify habitat complexity and relate it to fish distribution, shelter and recruitment.

Fish identification and abundance:

ROV/AUV cameras enable non-destructive recording of fish species, abundance, distribution and behaviour along standardized transects.

Detection probability and fish responses to vehicles should be considered.

Fish length estimation:

Stereo cameras and scaling lasers can estimate fish length without capture. These measurements can be combined with species-specific length–weight relationships to estimate biomass.

Biomass estimation:

Fish detection → Species identification → Length measurement → Length–weight relationship → Individual biomass → Population biomass. This integrated approach can support fisheries-independent biomass estimation and improve stock-assessment and management studies.

Contribution to Ecosystem-Based Fisheries Management

Underwater imaging provides fishery-independent observations that complement catch, effort and biological data. By linking habitat characteristics with fish distribution, abundance and biomass, photogrammetry can support ecosystem-based fisheries management.

Habitat characteristics → Fish distribution → Fish abundance → Biomass → Fisheries management

Photogrammetry and Marine Biodiversity Monitoring

Photogrammetry can monitor coral reefs, seagrass beds, sponge communities, rocky habitats, artificial reefs and benthic organisms. Repeated 3D surveys allow researchers to quantify changes in habitat structure and organismal characteristics, supporting long-term biodiversity monitoring.

Artificial Intelligence and Automated Image Analysis

AI, machine learning and computer vision can process large volumes of underwater imagery for fish detection, species identification, counting, size estimation, habitat classification and change detection. However, variations in lighting, turbidity, fish orientation and habitat complexity can affect accuracy, making expert validation and representative training datasets essential.

Recent Advances in AUV-Based Fisheries Surveys

Long-range AUVs are expanding the potential for large-scale, non-destructive fisheries surveys. Autonomous platforms can collect extensive imagery from areas difficult to sample using conventional gears. The integration of imagery, acoustic data, biological sampling,

environmental measurements, habitat maps and fisheries-dependent information can provide a more comprehensive basis for fisheries assessment and management.

Major Challenges

- Water turbidity: Reduces visibility and affects image matching.
- Light attenuation: Requires artificial lighting at greater depths.
- Refraction: Alters the optical path and requires camera calibration.
- Navigation uncertainty: Underwater GPS is unavailable, causing potential positioning errors.
- Battery limitations: Restrict AUV mission duration.
- ROV tether limitations: Restrict movement and may cause drag or entanglement.
- Data processing: Large image datasets require considerable storage and processing.
- Standardization: Differences in equipment and survey methods can affect data comparability (Marre et al., 2019; Remmers et al., 2024).

Future Directions

- Future underwater fisheries research will increasingly integrate multiple technologies rather than rely on a single method. A typical system may combine:
- AUV/ROV → High-resolution cameras → 3D photogrammetry → Sonar & bathymetry → Environmental sensors → AI → GIS & spatial modelling → Fish abundance and biomass estimation → Fisheries management
- This integrated approach, known as sensor fusion, combines visual, acoustic, positional, and environmental data to improve survey accuracy and coverage. Integration of photogrammetry with autonomous platforms is expected to enhance the scale, repeatability, and efficiency of marine ecological surveys (Pulido Mantas et al., 2023).

Conclusion

Underwater photogrammetry is an important technological advancement in marine and fisheries science, enabling overlapping images to be transformed into measurable three-dimensional models. Its integration with ROVs and AUVs facilitates research in deep, complex and inaccessible habitats, with applications in habitat mapping, biodiversity monitoring, fish measurement, abundance estimation and fisheries-independent surveys (Smale et al., 2012; Paterson et al., 2024). Despite limitations such as turbidity, light attenuation, refraction,

navigation constraints, battery capacity and data-processing requirements, appropriate calibration, standardized methods and uncertainty assessment can improve its reliability. Future underwater fisheries research will increasingly become multidisciplinary, automated and spatially explicit, integrating photogrammetry with sonar, AI, GIS and autonomous platforms. Ultimately, its greatest value lies in converting underwater structures and biological observations into quantitative ecological information for fisheries research, biodiversity conservation and sustainable marine-resource management.

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Volume: 06 Issue No: 10

LADYBIRD BEETLE: A FARMER-FRIENDLY INSECT IN AGRICULTURE

Article ID: AG-VO6-I10-30

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Abstract

Ladybird beetles, commonly known as ladybugs or ladybirds, are important beneficial insects belonging to the family *Coccinellidae* of the order Coleoptera. They play a significant role in sustainable agriculture by naturally controlling several economically important insect pests, particularly aphids, mealybugs, scale insects, whiteflies, and mites in some species. Both larvae and adults of many predatory ladybird beetle species actively feed on these pests, thereby reducing crop damage and helping maintain ecological balance in agricultural ecosystems. Their contribution to biological control can reduce dependence on chemical insecticides, minimize environmental pollution, and support integrated pest management (IPM) strategies. Ladybird beetles are beneficial in a wide range of agricultural and horticultural crops, including vegetables, fruits, pulses, and field crops. However, their effectiveness depends on species, prey availability, environmental conditions, and pesticide use. The conservation of these natural enemies through selective pesticide application, habitat management, and biodiversity-friendly farming practices is essential for sustainable crop protection. Therefore, ladybird beetles represent valuable natural allies of farmers and an important component of environmentally responsible agriculture.

Keywords: Aphids, Beneficial insects, Biological control, Coccinellidae, Crop protection, Ecological balance, Integrated pest management (IPM), Ladybird beetle, Natural enemies, Sustainable agriculture.

Introduction

As knowledge about insects increased, the name became extended to all its relatives, members of the beetle family *Coccinellidae*. Ladybird is a name that has been used in England for more than 600 years for the European beetle *Coccinella septempunctata*. In the USA, the name ladybird are popularly Americanized to ladybugs, although these insects are beetles, not bugs. Coccinellidae are the family of beetles belonging to the *superfamily Cucujoidea*, which in turn belongs to the series *Cucujiformia* within the suborders Polyphaga of the beetles. The lady bird beetle is a natural predator which has great contribution in biological control. It has long oval and dome shaped and variously coloured body, hemispherical in shape. The abiotic parameters are known to have direct impact on insect population dynamics and direct and indirect impact on Coccinellids through modulation of developmental rates, survival, fecundity, parasitism and dispersal. Seven-spotted ladybird beetles are predaceous on various types of aphids (rose aphid, green peach aphid, green bug aphid and green mustard aphid), mealy bugs, sugarcane aleyrodid, citrus psyllid, mites and sorghum stem borer, *Chilo partellus*. The predator has high potential of predation both in the immature as well as adult stage (Shepard, 1998).

1. Connection with the Virgin Mary

The name ladybird is believed to have originated in medieval European Christian traditions. The beetle was associated with the Virgin Mary, the mother of Jesus Christ, who was often referred to as Our Lady. The insect was historically called Our Lady's beetle, and the name gradually evolved into ladybird.

2. The Red Colour and Black Spots

The red or orange wings and black spots of the beetle became associated with religious symbolism. In some traditions, the seven spots of the seven-spotted ladybird were linked to the Seven Sorrows of Mary, referring to seven sorrows traditionally associated with the Virgin Mary. However, these associations are based on historical and religious traditions, and not every detail of the name's origin is definitively established.

3. Importance in Agriculture

Ladybird beetles are beneficial insects because they feed on harmful agricultural pests, particularly aphids. By reducing aphid populations, they help protect crops and support biological pest control. This makes them valuable allies of farmers.

Taxonomic Position

Kingdom - Animalia

Phylum- Arthropods

Class - Insecta

Order- Coleoptera

Sub Order- Polyphaga

Superfamily- Cucujoidea

Family- Coccinellidae

Biology: The ladybird beetle belongs to the family coccinellidae of order coleoptera.The members of the family are exclusively predator on aphids, mealybugs, scale-insects, whiteflies, thrips, leafhoppers, mites and other small soft bodied insect pests. Average length and breadth of larvae are. 41 ± 0.16 and 0.42 ± 0.02 mm, respectively. Average width of head capsule is 0.25 ± 0.02 mm. Mean length and breadth of pupae are 3.88 ± 0.19 mm and 2.30 ± 0.45 mm, respectively. Number of eggs laid by an individual female of ladybird beetle ranged from 195 to maximum 839 eggs with a mean of 382 ± 163.17 eggs. A female's fecundity under 25 °C temperature is about 400 eggs. The range is 200-700 eggs, on average 9 eggs/day.

Eggs: Tiny, bright yellow – orange, spindle shaped eggs laid upright in cluster of 5-30. Usually located near colonies of insect they eat. May be mistaken for egg of some pest beetle such as Colorado potato beetle, Mexican bean beetle and squash beetle.

Larvae: Look completely different from adults, being flattened and tapered. Alligator like body structure. Up to ¼ inch long. Usually dark coloured (Black) with orange or yellow markings. Many species have short bristles on some part of the body. Three prominent pairs of legs. Larva are very active, creeping about quickly as they hunt for prey.

Pupa: The pupae is the size of an adult ladybird however, it is all wrapped up at this stage of the metamorphosis. The wrapping protects the pupae while it undergoes the final stage of metamorphosis into the adult stage. This last stage only takes a few days.

Adult: Vary in size but average ¼ to 3/8 inch long. Typically round or oval and convex in shape. Bright and varied colours ranging from black to pink yellow or red with or without spots on wings.

Where to find?

Found on many plants throughout the garden and landscape. Found where abundant of its prey

and alternative foods are available, feeding on soft bodies insects or flowering plants. Look especially on leaf undersides.Garden crops on which lady beetles are commonly found includes potatoes, sweet corn, peas, cole crops, tomatoes and asparagus.

Commercial Availability

1. ***Cryptolaemus montrouzieri*** **-** Mealybug destroyer (mealybugs on citrus, ornamentals, and vegetables, and in greenhouses and interior - scapes).

2. ***Delphastus catalinae*** **-** Whitefly predator (greenhouse, banded-winged, sweet potato, woolly, azalea, hibiscus, cloudywinged, citrus and rhododendron whiteflies on ornamentals, vegetables, fruit, and citrus, and in greenhouses and interior - scapes).

3. ***Rhyzobius lophanthae*** **-** (also called *Lindorus lophanthae*) hard and soft scales and mealybugs on ornamentals.

4. ***Hippodamia convergens***- Ladybeetle (aphids, scales and thrips, in citrus, ornamentals, fruits and vegetables, and in greenhouses and interior - scapes). This species occurs in Florida but there still is a potential problem - some suppliers do not rear the beetles but collect overwintering adults from the mountains of eastern California - these overwintering adult beetles (a) may be heavily parasitized and many may die, and (b) may be programmed at the end of the winter to end the hibernation by flying west (which may do you no good if they all take to flight and leave your property). Coccinella spp. an important lady bird beetle in the Sub-Himalayan region of north –east India are found very active on different insect pest of brinjal throughout the year and its population are recorded higher (4.87 coccinella/plant) during March – April declined gradually. Coccinella incidence showed significant positive correlation with maximum temperature where as with minimum and mean temperature and rainfall correlation are negative but non significant. Coccinella lady bird beetle population found higher (3-5/plant) during 3rd and 4th week of july in active vegetative growth of the crop. Adult and larval *Adalia bipunctata, Coccinella septempunctata* and *Harmonia axyridis* would consume more aphid biomass per body weight at rising temperature and would gain more body weight at rising temperature.

Effect on predatory potential

Lower foliar nitrogen content due to CO2 causes an increase in food con- sumption by the herbivores up to 40% (Sharma *et al*., 2010). For instance, cotton is attacked by aphids, *Aphis gossypii,* which are in turn attacked by the ladybird beetle. Under elevated CO2, cotton aphid

survival significantly increased but ladybird larval development took significantly longer time (Gao *et al*., 2009). The coccinellid predator, *Leis axyridis* Pallas (Coleoptera: Coccinellidae), of an aphid herbivore, Aphis *gossypii Glover* (Hemiptera: Aphididae), consumed more prey under conditions of higher CO2 (Chen *et al*., 2005). Chen *et al*. (2007).

Effect on inter-specific population interaction

First, insects generally have a minimum temperature required for development, and this development threshold can differ between bio-control agents and their hosts. When the threshold is lower in the host than in the enemy, then pest suppression should increase with warming (GTR declines). If the thermal development threshold is higher in the host than in the enemy, then warming may reduce pest suppression (GTR increases). While the GTR has been shown to be a strong predictor of prey suppression by predators (Kindlmann and Dixon, 1999), the theory has also been applied to parasitoid-host systems (Mills, 2006).

Effect on parasitism

The life of a developing parasitoid depends on suppressing or fooling the host's immune system. Studies suggest that higher temperatures increase the probability that a host will kill its parasitoid. Parasitism of the caterpillar *Spodoptera littoralis* by the parasitoid *Microplitis rufiventris* is less at 27°C (80.6°F) than at 20°C (68°F) (Thomas and Blanford 2003). Natural enemies of the spruce budworm, *Choristoneura fumiferana,* are less effective at higher temperatures (Harrington *et al*. 2001).

Effect on coloration

Insect coloration is the phenomenon of adoption to maintain the heat. Basically darker colours are employed to absorb the heat and paler colours to avoid or reduce the heating. Scientists have noticed that warming climate is changing ladybugs of the coast of Netherlands from black to red. Red reflects more energy hence ladybugs stay cool. The difference between red and black in ladybugs is only one protein, so as far as genetic adaptations concerns, it's an easy switch.

How Climate change effect our abilities to manage pest?

Climate change may also indirectly affect insect herbivores; for example, excessive heat or drought create stress on trees and lower their defence, making them less resistant to insect attacks (Ayres, 1993). Casteel *et al*. (2009). Reported that global warming could cause another deleterious effect in the form of deactivation of some genes responsible for the production of

volatile substances that are used by plants to attract the natural enemies of the herbivorous insects. Vuorinen *et al*., (2004). Reported that, in cabbage elevated CO2 level decreased the emission of Jasmonic acid regulated terpene volatiles that reduced the searching efficiency of the parasitoid, *Cotesia plutellae.*

Combined effects of temperature and CO2 on natural enemy

increased temperature allow moths (leaf miner) to develop a lot more quickly, but increased CO2 causes the nutritional qualities in the leaves to change, which results in smaller adult moths and lower rate of survival in the adults. In other words, when considering climate change, we must also consider that some factors may balance each other out.

Effects of the winter temperature regime on survival of lady bird beetle

The warm winter regime increased the survival rate and body mass loss and reduced post-winter starvation resistance compared to those of the ladybirds in the cold winter regime. The winter survival of the laboratory-reared beetles are much lower than that of the field-collected beetles. The laboratory-reared beetles also lost a larger proportion of their body mass and had reduced post-winter starvation resistance. Winter survival are similar between the females and males, but compared to the males, the females lost a smaller proportion of their body mass and had better post-winter starvation resistance.

Potential impact of ladybird beetle on bio-control

Results revealed that aphids were slightly more preferred (53.8%) as compared to mealy bugs (46.2%) when both were exposed together to adult of *Coccinella septempunctata* in free choice test. In no choice test, when aphids and mealy bugs were fed individually to *Coccinella septempuctata*, the predation of mealy bugs are 80 per cent after 24 hours; however it increased to 84.7 per cent after 96 hours. The overall mealy bugs consumption varied from 24.0 ± 0.77 to 25.40 ± 0.98 per day. The mean number of aphids consumed the predator varied from 26.00 ± 0.81 to 28.00 ± 0.71 per day and the percent predation are 88.7 per cent after 24 hours and it increased to 93.3 per cent after 96 hours. Larval development of *C. sexmaculata* are long when fed on *M. persicae* (12.18 days) and shorter on *D. noxia* (10.64 days). The male's lifespan are longer on *M. persicae* (26.70 days) and shorter on *L. erysimi* (23.67 days). Fecundity are maximum when the beetle are fed *D. noxia* (316.8 eggs/female) and minimum on *M. persicae* (199.1 eggs/female). Female beetle devour more aphid as compare to male, the 4th instar grub

prefer more aphid than any other larval instar. Feeding efficiency of lady bird beetle revealed that individual grub required 610.25 aphids for completion of larval development.

Conclusion

Effect of climate change is more in temperate areas; it can affect the range expansion, host and enemy synchrony and inter-specific competition. Among the various abiotic factors, temperature is an important force to drive the natural enemy population. It can cause the direct effects like survival, growth and development, volatinism, longevity, parasitism and dispersal of natural enemies. Adverse effects of climate change on the activity and effectiveness of natural enemies will be a major concern in future pest management programs. The CO2 cause indirect effect through host nutrient alteration and it has both positive and negative effects. Therefore, there is a need to have a concerted look at the likely effects of climate change on crop protection and long-term conservation bio control agents, which need greater attention to understand and address these issues through more research.

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Volume: 06 Issue No: 10

UZI FLY AND ITS MANAGEMENT IN SILKWORM

Article ID: AG-VO6-I10-31

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Abstract

The uzi fly, *Exorista bombycis*, is one of the most persistent parasitoid pests affecting mulberry silkworm rearing in India. Its infestation can reduce cocoon yield and quality, particularly during the fourth and fifth instars when silkworms are highly vulnerable. This article highlights the biology and life cycle of the uzi fly, symptoms of infestation, its economic importance, and the factors that favour its spread. It also discusses integrated management approaches, including physical exclusion, rearing-house sanitation, ovicidal treatments, biological control using *Nesolynx thymus*, botanical products, trapping and seasonal planning. Understanding the pest and combining these measures can help farmers reduce infestation, protect silkworm crops and improve cocoon production.

Introduction

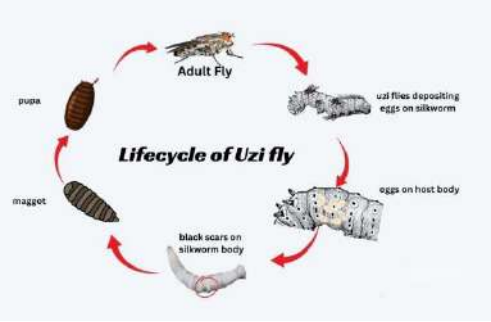
The uzi fly is a tachinid fly, *Exorista bombycis* (Louis). It belongs to the family Tachinidae, a large group of flies whose larvae develop as parasitoids inside other insects. Several related species attack silkworms elsewhere in Asia, including the Japanese uzi fly, *Crossocosmia sericariae*, the Hime uzi fly, *Ctenophorocera pavida*, and the tasar uzi fly, *Blepharipa zebina*, which targets tasar rather than mulberry silkworms. In Indian mulberry

sericulture, though, *Exorista bombycis* accounts for most of the damage, and a closely related tachinid has also been implicated in serious losses to muga silkworm rearing in the northeastern states.

Adult uzi flies look something like house flies, only larger and more heavily bristled, a feature typical of the Tachinidae family. Unlike a general scavenging fly, though, the female is a specialist hunter. She locates host larvae partly through odor cues released by the feeding silkworm, and she shows a marked preference for fourth and fifth instar larvae, since these older, larger caterpillars offer more tissue for her maggots to grow in. Eggs are usually glued to the dorsal surface of the host, in the intersegmental grooves where the cuticle is thinner and easier for the newly hatched maggot to penetrate. Over her reproductive life a single female can lay several hundred eggs, with reported figures ranging from around three hundred up to eight hundred depending on the study, which goes some way toward explaining how quickly an unchecked population builds up inside a rearing house.

Biology and Life Cycle

The uzi fly passes through the four familiar stages of complete metamorphosis, egg, maggot, pupa, and adult, though each stage has features that matter directly to a rearer trying to interrupt the cycle.



The egg is small, oval, and pale, glued firmly enough to the host's cuticle that it cannot easily be brushed off. Development inside is quick, and the first instar maggot bores through the host's body wall almost as soon as it hatches, reaching the hemocoel within hours. Once inside, it passes through three larval instars while feeding on the silkworm's internal tissues, and this internal feeding period is short, generally only four to five days, even though the silkworm may keep feeding and appear outwardly normal for part of that time. The first visible sign at the entry point is a small brown lesion, which over the following days enlarges into a raised, blackish, horn shaped sheath as the silkworm continues to grow around the wound. Parasitized larvae sometimes take on a faint purplish tinge from oxidized hemolymph, a detail experienced rearers learn to watch for.

When the maggot finishes developing it emerges from the host, usually killing the silkworm in the process, and drops to the rearing bed or tray to pupate. The pupal stage runs roughly ten to twelve days under favorable conditions, though pupae forming late in the season can enter diapause and remain dormant for several months, a strategy that lets the pest carry over from one rearing cycle to the next. Adults then live for a matter of days to a couple of weeks, mate, and the females begin host seeking again, closing the loop.

Exorista bombycis is not restricted to the mulberry silkworm alone. It is a generalist parasitoid capable of developing in more than ten other lepidopteran species, so populations can persist in the surrounding landscape on alternative hosts even when no silkworms are being reared, then move into rearing houses once a fresh larval crop becomes available.

Recognizing an Infestation



An experienced rearer learns to watch for a fairly consistent set of signs. Small, pale, oval eggs may be visible glued to the dorsal segments of fourth and fifth instar larvae. Infested larvae often become restless, feed irregularly, and develop a small brown lesion near the point of egg attachment that darkens and enlarges as the maggot grows beneath the skin. As the infestation progresses, affected larvae may take on a purplish discoloration, fail to reach normal size, and eventually die as one or more maggots emerge from the body. Small, dark brown, barrel shaped puparia scattered across the rearing tray or bed are often the first thing a farmer actually notices, and by that point the current crop has already taken a hit, with the puparia representing the next generation of flies waiting to emerge.

Economic Significance

The damage uzi fly causes to Indian sericulture has been documented for decades, and the figures, while variable across studies, are consistently significant. Some assessments put typical losses at twelve to twenty percent of the crop, while other field surveys, particularly of unprotected rearing during humid seasons, report losses as high as fifty percent. Damage tends to concentrate in two windows within a rearing cycle, during the fourth and fifth instar period when the flies preferentially oviposit, and again at harvest, when parasitized larvae fail to spin normal cocoons or die before completing spinning, cutting into both cocoon quantity and quality at once. Season and region both shape the scale of the problem. Warm, humid conditions favor rapid fly population growth, so infestation tends to be worse during the rainy and post monsoon crops and

comparatively milder when rearing is timed for drier, cooler months and carried out under proper physical protection. Studies from Karnataka have found that summer rearing under precautionary cover consistently gives better yield with lower uzi fly pressure than rearing carried out in wetter parts of the year, and similar seasonal patterns have been reported from West Bengal and from the muga growing tracts of the northeast, where uzi fly damage has at times reached a quarter of the crop during particular cropping windows.

Integrated Management Programme

No single tactic eliminates the uzi fly on its own, and decades of trial work in India point firmly toward combining several complementary approaches rather than relying on any one method. Physical exclusion is really the foundation everything else builds on. Fitting rearing house windows, ventilators, and doors with fine wire mesh or nylon netting keeps adult flies from entering the rearing space at all, and covering individual trays with a fly proof nylon net during the fourth and fifth instar period, when oviposition risk peaks, adds a second layer of protection. It costs relatively little, needs no chemical inputs, and researchers reviewing decades of uzi fly control work have repeatedly pointed to it as the most economical and environmentally sound option a farmer has.

Good rearing house hygiene supports that exclusion rather than replacing it. Prompt removal of larval frass, moulted skins, and dead or dying larvae limits the material that can attract flies or shelter puparia unnoticed, and keeping the area around the rearing house clear of decaying organic matter, which can serve as alternative breeding or resting sites for adults, further reduces the local population pressure bearing on the crop.

Ovicidal treatments aim to stop the problem before it starts, killing the egg before it can hatch. A dilute bleaching powder solution, or a formulated liquid preparation sold as Uzicide, has been used for decades to treat larval beds, and at recommended concentrations it kills uzi fly eggs without harming the silkworms. Timing matters here more than almost anywhere else in the programme, since sprays give their best results when applied through the fourth and fifth instar period, exactly when the crop is most attractive to egg laying females.

Biological control brings in a longer term, self sustaining dimension that chemical sprays cannot offer on their own. Several hymenopteran parasitoids attack the uzi fly's own pupal stage, effectively turning its reproduction against it, and *Nesolynx thymus* is by far the best studied and most widely deployed of these. Field trials involving augmentative release of laboratory reared

adults, sometimes running into millions of individuals released across hundreds of rearings in a single season, have shown sustained suppression of uzi fly numbers when the releases are combined with ovicidal spraying. Other parasitoids recorded attacking uzi fly puparia include *Trichomalopsis apanteloctena*, *Trichopria* species, *Brachymeria lasus*, *Pediobius* species, *Spalangia* species, and *Dirhinus* species, though *Nesolynx thymus* remains the one most extension programmes actually rely on for practical release.

Insect growth regulators fill a smaller, supporting role. Dusting with compounds such as diflubenzuron has been tested as a way of reducing the reproductive success of any flies that do manage to lay eggs, and it works best as one piece of a broader programme rather than a standalone answer.Botanical extracts are where a good deal of current research energy is going. Leaf extracts from various plants have been screened as ovipositional deterrents and as ovicidal or maggoticidal agents, and they are attractive for being biodegradable, low in mammalian toxicity, and gentler on the silkworms than synthetic sprays, though this line of work remains under active investigation rather than a settled farm level recommendation.

Trapping technology is the newest addition to the toolkit. Purpose built traps designed to attract and capture adult uzi flies without harming silkworms have been developed and are increasingly promoted as a low cost, chemical free way to thin the adult population in and around rearing houses, complementing rather than replacing the older exclusion and biological control practices.Finally, seasonal planning reduces exposure before any of the other measures are even needed. Where the rearing calendar allows flexibility, scheduling crops for drier, cooler periods and away from peak uzi fly activity in the rainy season lowers the baseline pressure that everything else then has to work against.

Future Perspectives

Current work on uzi fly management is moving in a few clear directions. One is refining mass rearing and release protocols for *Nesolynx thymus* and other pupal parasitoids, so augmentative biological control becomes accessible and affordable at the level of individual rearing houses rather than only larger cooperative programmes. Another is the continued screening of plant derived compounds for ovipositional deterrence, which fits the broader push toward reducing chemical inputs in sericulture. A third is the development and field testing of better adult trapping devices, giving farmers a passive, low maintenance option to run alongside their exclusion and spraying practices. Studies of how the fly locates its host, including its

apparent reliance on chemical cues from feeding larvae, may eventually open further angles for disrupting egg laying before it ever happens.

Conclusion

The uzi fly is not going away as a challenge in tropical sericulture, and no single treatment offers a complete solution on its own. What decades of research and field experience have produced instead is a genuinely workable integrated package, exclusion netting as the non negotiable baseline, ovicidal sprays timed to the vulnerable fourth and fifth instar period, sustained release of pupal parasitoids such as *Nesolynx thymus*, good rearing house sanitation, and attentive seasonal planning. Applied together and kept up season after season, these measures turn what farmers once treated as an unavoidable loss into a manageable part of the rearing cycle, protecting both cocoon yield and the income that depends on it.

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Integrated pest management of uzi fly (Exorista sorbillans) in Muga silkworm Antheraea assamensis Helfer: A review

Volume: 06 Issue No: 10

WATER LOGGING: CAUSES AND ITS ALLEVIATION IN PLANTS

Article ID: AG-VO6-I10-32

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Introduction

Water Logging: Water logging is a condition in which the soil becomes saturated with water for a prolonged period, causing most or all of the soil pores to be filled with water. As a result, the supply of oxygen to plant roots is greatly reduced or completely stopped. Under normal conditions, soil contains both water and air. Water logging replaces the air in soil pores, producing oxygen deficiency (hypoxia) or complete absence of oxygen (anoxia) around the roots. Water logging is particularly harmful to crops because roots require oxygen for respiration, nutrient uptake and normal metabolic activities.

Types of Water Logging: Water logging can be classified in several ways:

A. Natural Water Logging: Occurs naturally because of:

- Heavy or prolonged rainfall Flooding of rivers and streams
- Poor natural drainage Low-lying topography
- High groundwater table

B. Artificial or Man-Made Water Logging: Develops because of human activities such as:

- Excessive irrigation Poorly designed irrigation systems
- Leakage from canals and water channels Inadequate drainage systems
- Improper land leveling

C. Surface Water Logging: Water accumulates on the **soil surface** because rainfall or irrigation exceeds the infiltration and drainage capacity of the soil.

D. Subsurface Water Logging: The water table rises close to the root zone, saturating the soil below the surface.

E. Temporary Water Logging: Occurs for a short period after heavy rainfall or irrigation. Some crops can tolerate this condition if drainage occurs quickly.

F. Permanent or Prolonged Water Logging: Soil remains saturated for a long period because of a continuously high water table or poor drainage. It is generally much more damaging to crops.

Causes of Water Logging: Major causes include:

1. Excessive Irrigation: Applying more water than the crop requires increases soil moisture and may raise the groundwater table.

2. Poor Drainage: Clayey and compact soils have low permeability, so excess water cannot move away rapidly.

3. Heavy Rainfall: Continuous or intense rainfall can saturate the soil, particularly when drainage is inadequate.

4. High Water Table: A shallow groundwater table can bring water into the root zone through capillary movement.

5. Flooding: Floodwater can cover agricultural fields and create prolonged soil saturation.

6. Impermeable Soil Layer: A hardpan or compacted layer below the surface restricts downward movement of water.

7. Canal Seepage: Unlined canals and irrigation channels may lose large quantities of water into surrounding soil, increasing the groundwater level.

8. Poor Land Leveling: Uneven fields allow water to collect in depressions.

9. Soil Compaction: Farm machinery and repeated cultivation can reduce soil pore space and infiltration.

10. Inadequate Drainage Infrastructure: Lack of surface drains, subsurface drains and proper water-management systems can aggravate water logging.

Mechanism of Water Logging

The main mechanism can be summarized as:

Excess water → soil pore saturation → displacement of air → oxygen deficiency → reduced root respiration → reduced ATP production → impaired nutrient and water uptake → accumulation of toxic substances → reduced growth and yield

Step 1 Soil Pore Saturation: Excess water fills the large and small soil pores.

Step 2 Reduction in Oxygen: Water moves into spaces normally occupied by air. Since oxygen moves through water much more slowly than through air, oxygen supply to roots rapidly decreases.

Step 3 Root Hypoxia/Anoxia: Roots experience **hypoxia** when oxygen concentration becomes very low and **anoxia** when oxygen is nearly absent.

Step 4 Reduced Aerobic Respiration: Mitochondrial aerobic respiration decreases, resulting in reduced production of **ATP**, the energy currency required for cellular processes.

Step 5 Anaerobic Metabolism: Roots increasingly depend on anaerobic fermentation. This produces much less energy and may result in accumulation of compounds such as ethanol and lactate.

Step 6 Changes in Soil Chemistry: Water logging causes soil to become strongly reducing. The availability and chemical forms of nutrients such as iron, manganese and sulfur change, while toxic concentrations of some reduced compounds may develop.

Step 7: Root Damage: Root growth, membrane function, nutrient absorption and overall root activity decline. Some plants respond by developing aerenchyma, specialized air spaces that facilitate oxygen movement from shoots to roots.

Effects of Water Logging on Plants

A. Effects on Roots

- Reduction in root respiration
- Poor root growth
- Root death under prolonged stress
- Reduced root branching
- Reduced nutrient absorption
- Reduced root hydraulic conductivity

B. Effects on Shoots

Waterlogged plants commonly show:

- Leaf yellowing (**chlorosis**)
- Premature leaf senescence
- Wilting despite abundant soil water
- Reduced leaf area
- Reduced shoot growth
- Stunted plants
- Premature leaf and fruit drop

C. Effects on Photosynthesis

Water logging reduces photosynthesis because of:

- Reduced stomatal conductance
- Reduced CO_2 uptake
- Nutrient deficiencies
- Chlorophyll degradation

- Reduced leaf expansion Damage to photosynthetic machinery under severe stress

D. Effects on Nutrient Uptake: Water logging can interfere with the availability and uptake of:

- Nitrogen Phosphorus Potassium Iron
- Zinc and other micronutrients

Nitrogen losses can be particularly important because oxygen-poor soils promote denitrification, converting nitrate into gaseous nitrogen forms.

E. Effects on Plant Hormones: Water logging alters hormonal balance. It may increase ethylene production and modify the levels and transport of hormones such as auxin and abscisic acid. These changes influence root growth, leaf responses and the formation of adaptive structures.

F. Effects on Yield: Severe or prolonged water logging can cause:

- Poor flowering Reduced fruit/seed formation
- Poor grain filling Reduced fruit quality
- Premature fruit drop Significant reduction in crop yield
- In extreme cases, complete crop failure

Mitigation of Water Logging

Water logging can be controlled through **proper drainage, irrigation and soil management**.

1. Improve Surface Drainage: Construct open drains to remove excess surface water from fields.

2. Install Subsurface Drainage: Tile or pipe drainage can lower the water table and remove excess water from the root zone.

3. Proper Irrigation Management: Apply irrigation according to crop requirements.

- Avoid unnecessary irrigation.
- Use drip or other efficient irrigation systems where appropriate.
- Monitor soil moisture before irrigation.

4. Proper Land Leveling: Laser or precision land leveling helps distribute irrigation water uniformly and reduces stagnant water.

5. Raised Beds and Ridges: Growing crops on raised beds, ridges or mounds improves root-zone drainage and is particularly useful for sensitive crops.

6. Improve Soil Structure: Addition of suitable organic matter and avoidance of excessive compaction can improve infiltration and aeration.

7. Control Canal Seepage: Proper lining and maintenance of irrigation canals can reduce seepage and prevent unnecessary groundwater recharge.

8. Use Water-Logging-Tolerant Crops or Varieties: Where water logging cannot be completely avoided, select tolerant varieties or crops adapted to temporary flooding.

9. Proper Field Drainage During Heavy Rain: Provide drainage outlets so that accumulated rainwater can leave the field quickly.

10. Biological and Agronomic Approaches: Certain crops and varieties can tolerate water logging through adaptations such as:

- Aerenchyma formation
- Adventitious root development
- Enhanced internal oxygen transport
- Improved carbohydrate conservation

Summary: Water logging is the prolonged saturation of soil with water, resulting in inadequate oxygen availability to plant roots. It may be caused by excessive irrigation, heavy rainfall, flooding, poor drainage, high groundwater level, soil compaction and canal seepage. The most important physiological effect is root oxygen deficiency. Reduced oxygen decreases aerobic respiration and ATP production, disrupts nutrient uptake and causes metabolic and biochemical changes. Consequently, plants may show poor root development, chlorosis, wilting, reduced photosynthesis, premature senescence and reduced yield. Water logging can be managed by efficient irrigation, surface and subsurface drainage, proper land leveling, raised beds, improved soil structure, control of canal seepage and cultivation of water-logging-tolerant varieties.

Simple flow chart

Excess rainfall/irrigation
↓
Soil saturation
↓
Air displaced from soil pores
↓
Root-zone oxygen deficiency
↓
Reduced root respiration and ATP production
↓
Poor nutrient uptake + root injury
↓
Reduced photosynthesis and growth
↓
Reduced crop yield and quality

Summary: Waterlogging occurs when soil becomes completely saturated with water, filling up the air spaces (pores) in the soil and preventing adequate drainage. This creates an **anaerobic (oxygen-depleted) environment** that severely limits the amount of oxygen available to plant roots 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: 10

SOIL STRUCTURE STABILITY THROUGH NANO-SILICA AND CARBON NANOTUBES

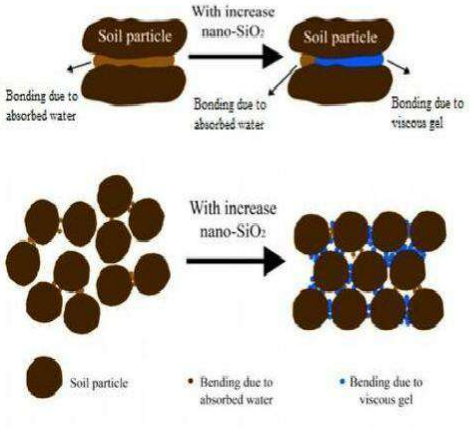
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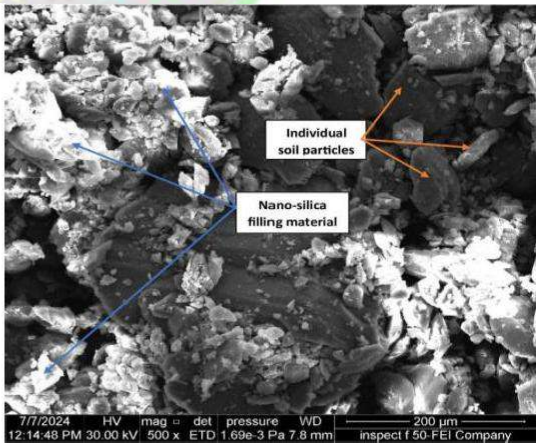
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Introduction

Soil is much more than a mixture of sand, silt, clay, water and organic matter. At the microscopic level, soil particles are arranged into aggregates—small clusters that determine how easily water, air and roots move through the soil. When these aggregates remain stable during rainfall, irrigation and drying, the soil has better resistance to erosion and maintains a favorable pore structure. Recent research suggests that nanomaterials such as nano-silica (SiO_2 nanoparticles) and carbon nanotubes (CNTs) may help modify the contacts between soil particles and improve soil structural stability. However, most evidence is still from laboratory and controlled experiments, so their agricultural use requires careful evaluation.





1. *What is soil structure stability?*

Good soil structure means that individual soil particles are held together in stable aggregates while leaving interconnected pores between them.

A stable soil structure provides:

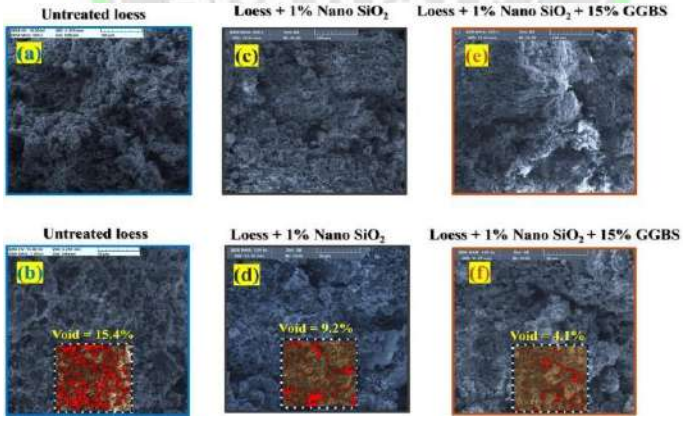
- better water infiltration,
- improved water-holding capacity,
- adequate air movement,
- greater resistance to erosion,
- improved root penetration,
- reduced compaction,
- better nutrient retention.

During heavy rainfall, unstable aggregates can break apart and disperse. During prolonged drying, soil can shrink and develop cracks. Repeated wetting–drying cycles can therefore gradually damage soil structure.

Silica is naturally involved in soil aggregation, and research has shown that silica and organic carbon can interact to influence aggregate stability during drying.

2. *Nano-silica: a tiny material with a large surface*

Nano-silica consists of extremely small particles of silicon dioxide, generally in the nanometre range. Because the particles are so small, they have a very large surface area relative to their mass.

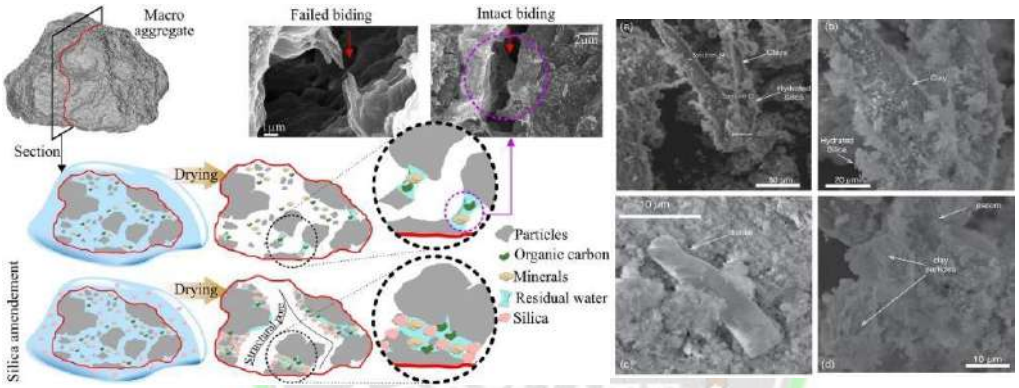


When nano-silica is introduced into soil, several mechanisms may occur Nano-silica particles can enter spaces between larger soil particles. This can reduce some large voids and create a more closely packed soil matrix. The large surface area of nano-silica allows it to interact with clay minerals and other soil components. These interactions can increase bonding between particles. Research on nanosilica-treated soils has found that nanoparticles can fill pores and increase the effective contact area between soil particles. At appropriate

concentrations, this can increase cohesion and improve mechanical strength. Silica does not necessarily work alone. Organic carbon can interact with silica surfaces and influence the stability and density of soil aggregates. A 2024 study reported that silica enhanced the positive effect of organic carbon on structural stability during drying.

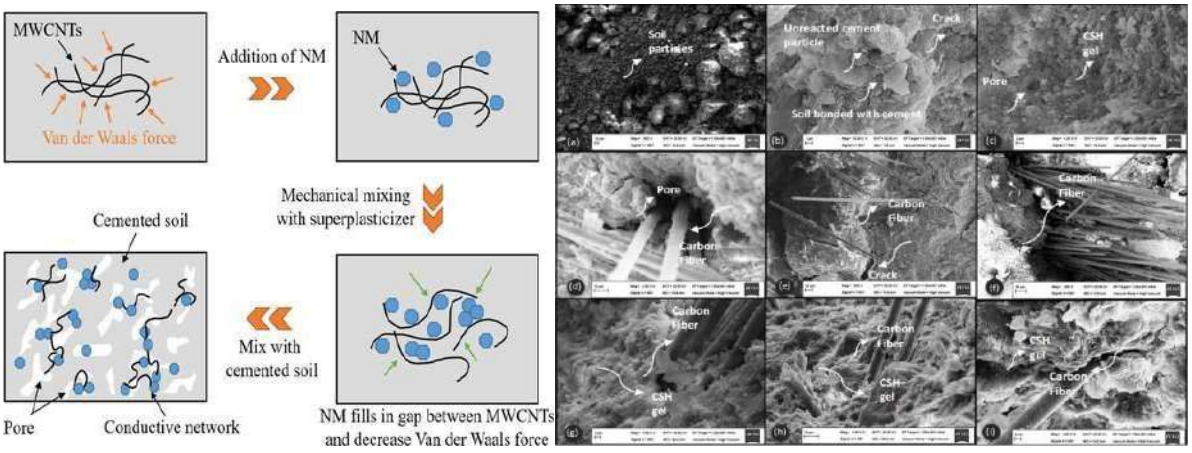
3. How nano-silica can stabilize soil aggregates

Nano-silica is particularly interesting because its very small particle size provides a large reactive surface area. However, too much nano-silica can cause particle aggregation (agglomeration), so the concentration and dispersion conditions are important. Research reviews also report that the effects vary according to soil type and treatment concentration.



4. Carbon nanotubes: microscopic reinforcing fibres

Carbon nanotubes (CNTs) are cylindrical carbon nanostructures with extremely high aspect ratios and remarkable mechanical properties. Their structure makes them interesting as a possible nano-reinforcement for soil. Instead of simply filling pores, CNTs can behave somewhat like extremely small reinforcing fibres.



1. ***Nano-silica and CNTs: different mechanisms, complementary possibilities***

The two materials can be thought of as performing different functions.

Material	*Possible function in soil*
Nano-silica	Fine pore filling, surface bonding and particle packing
Carbon nanotubes	Nano-scale reinforcement and bridging of particles/cracks
Nano-silica + organic carbon	Potentially enhanced aggregate stability
CNTs + soil particles	Improved stress transfer and resistance to cracking

Nano-silica primarily works through its very small particle size, large surface area and surface interactions, whereas CNTs have a distinctive high-aspect-ratio fibrous structure. A recent review of nano-enabled agriculture reported that carbon nanotubes have been associated with improved aggregation in sandy-loam soil, while nanomaterials more generally can influence soil porosity, bulk density and water movement.

2. ***Why stable soil aggregates matter for agriculture***

The importance of soil structure becomes clearer when we consider the plant root zone. A well-aggregated soil provides a balance between: solid particles + water-filled pores + air-filled pores This balance allows roots to obtain water and oxygen simultaneously. Stable aggregates can also reduce the susceptibility of soil to erosion. When aggregates resist breakdown under water, fewer fine particles are detached and transported away. This is particularly important in agricultural soils exposed to:

- intense rainfall,
- irrigation,
- drought,
- repeated cultivation,
- compaction,
- loss of organic matter.

Recent research on rice-husk-derived nanosilica, for example, investigated wet aggregate stability and soil detachment in paddy soils, highlighting the potential of silica nanomaterials for improving soil structural characteristics. Nano-silica may occupy very small spaces and strengthen interfaces, while CNTs may provide elongated reinforcing structures. In principle, this creates a nano-scale network within the soil matrix.However, this combined concept should not be presented as an established agricultural technology: research specifically

testing nano-silica + CNTs together for long-term field-scale soil aggregation remains much more limited than research on each material separately.

8. Important limitations and environmental concerns

Nanotechnology offers exciting possibilities, but soil is a complex biological system. Introducing engineered nanoparticles can affect not only soil particles but also microorganisms, earthworms, roots and nutrient cycles. For CNTs in particular, their environmental behavior depends strongly on factors such as aggregation, soil texture, organic matter and mobility. There are also practical challenges:

- high production cost of some nanomaterials,
- difficulty achieving uniform dispersion,
- nanoparticle aggregation,
- uncertainty about long-term environmental effects,
- possible effects on soil microorganisms,
- difficulty scaling laboratory treatments to agricultural fields.

Therefore, optimum concentration is critical. A material that improves soil at one concentration may have little benefit—or even undesirable effects—at another

9. Future prospects

The future of nano-enabled soil management is likely to focus less on simply adding nanoparticles and more on designing smart, sustainable nano-amendments. One particularly promising direction is the production of silica nanoparticles from agricultural residues such as rice husk. This could combine waste valorization with soil improvement. A 2026 study specifically investigated rice-husk-derived nanosilica for improving structural stability in paddy soils.

Future research should investigate:

1. Nano-silica derived from agricultural wastes
2. Low-dose applications
3. Nano-silica–organic carbon interactions
4. CNT–soil aggregate interactions
5. Long-term effects on soil microorganisms
6. Effects under repeated wetting–drying cycles
7. Field-scale application rather than only laboratory experiments

8. Cost and environmental life-cycle assessment

The ultimate goal should be a soil amendment that improves structure without damaging the biological and ecological functions of soil.

Conclusion

Nano-silica and carbon nanotubes represent two different approaches to improving soil structural stability. Nano-silica can act as a fine-scale filler and surface-active material, improving particle contacts and modifying pore structure, while carbon nanotubes can provide nano-scale reinforcement and bridging between particles and cracks. Research supports the potential of these materials for soil stabilization, but their use in agricultural soils remains an emerging field rather than a universally established practice. The most promising future may lie in combining nanotechnology with organic matter management, biochar, compost and conservation agriculture, rather than using nanoparticles as a standalone replacement for good soil management.

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Volume: 06 Issue No: 10

SCOPE OF QUEEN REARING AND COLONY DIVISION IN THE STINGLESS BEE, *TETRAGONULA IRIDIPENNIS* SMITH (HYMENOPTERA : APIDAE) : A REVIEW

Article ID: AG-VO6-I10-34

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Abstract

The stingless bee *Tetragonula iridipennis* Smith is an important meliponine bee of India with considerable potential for crop pollination, honey and hive-product production, biodiversity conservation and rural entrepreneurship. Limited availability of colonies and slow natural colony multiplication are major constraints to large-scale meliponiculture. Queen production and artificial colony division are therefore important approaches for increasing colony numbers. In *T. iridipennis*, gynes and queen cells play a central role in colony multiplication. Studies in Tamil Nadu have demonstrated successful colony division using natural queen cells, while subsequent work has shown that emergency queen cells can be induced even when natural queen cells are absent. More recent experiments have demonstrated high success when gynes or queen cells are included during artificial division. In-vitro queen rearing has also emerged as a promising technology for producing queens independently of naturally occurring queen cells. This review summarizes the biological basis, methods, scope, constraints and future prospects of queen rearing and colony division in *T. iridipennis*, with emphasis on Indian meliponiculture.

Keywords: *Tetragonula iridipennis*, stingless bee, queen rearing, gyne, queen cell, colony division, colony multiplication, meliponiculture, pollination.

1. Introduction

Stingless bees (Apidae: Meliponini) are important eusocial pollinators of tropical and subtropical ecosystems. Their management, known as meliponiculture, is gaining importance for

crop pollination, production of honey and other hive products and biodiversity conservation. *Tetragonula iridipennis* is one of the important stingless bees occurring in India and is particularly relevant to southern Indian meliponiculture.

The availability of healthy colonies is a major limitation to the expansion of stingless-bee rearing. Dependence on natural colonies is inadequate for commercial multiplication and may also result in destructive removal of wild nests. Natural colony multiplication is relatively slow and seasonal. Recent research has identified slow natural multiplication and inadequate management technologies as important constraints to wider adoption of stingless-bee culture in South and Southeast Asia.

Artificial colony division provides a practical means of increasing colony numbers from strong managed colonies. However, successful establishment depends largely on the availability of a viable reproductive female, either as a gyne or queen cell (Fig. 1). Consequently, queen production is becoming an important component of scientific meliponiculture.

2. Queen production in *Tetragonula iridipennis*

The reproductive female of a stingless-bee colony is the physogastric queen, while an unmated reproductive female is generally termed a gyne. Queen production in stingless bees differs from conventional queen rearing in *Apis*. Gynes are periodically produced in colonies and their production is influenced by colony strength, food availability, reproductive condition and environmental factors.



Fig. 1 Natural or existing queen cell

Larval nutrition is particularly important in queen development. Recent research on *T. iridipennis* demonstrated that the larval provision required for queen development was approximately three times that supplied to a natural worker larva. An in-vitro queen-rearing

protocol produced queens morphologically similar to natural queens, with reproductive success supporting the feasibility of the technique.

Thus, queen production provides an important biological foundation for systematic colony multiplication.

3. Colony division using natural queen cells

The simplest method of artificial propagation is to divide a strong colony when natural queen cells are available. A suitable breeder colony should have a dense worker population, substantial brood, adequate pollen and honey stores and a healthy queen.

An important study conducted at Tamil Nadu Agricultural University demonstrated the feasibility of this approach. *T. iridipennis* colonies were divided successfully and established following gyne emergence with subsequent egg laying by the new queen (Fig. 2). The successful daughter colonies took 50 to 60 days to establish. The study demonstrated that strong colonies containing royal queen cells can be multiplied through careful colony division.



Fig. 2 Gyne emerged after division of the colony

4. Division without natural queen cells

Dependence on naturally produced queen cells limits the frequency of multiplication. Research at TNAU therefore examined whether strong colonies could be divided without an existing queen cell and induced to produce emergency queen cells.

Strong queen-right colonies with dense populations, developed brood and adequate pollen and honey stores were divided. In one treatment, natural queen cells were transferred to the queenless portion; in another, colonies were divided without natural queen cells to induce emergency queen-cell production. The two methods produced comparable numbers of queen cells, gynes and developing brood during the observation period.

This finding is important because it indicates that colony multiplication need not always wait for natural queen-cell production. TNAU subsequently identified emergency queen-cell production as a potential technology for adoption, reporting a faster production period and increased queen production under the experimental conditions.

5. Recent advances in artificial colony division

Recent research has further demonstrated the importance of gynes and queen cells in successful colony establishment. A 2025 study evaluated six artificial division methods involving 18 *T. iridipennis* colonies. Separation of brood with gynes recorded the highest success rate (66.66%). Divisions without gynes or queen cells recorded 33.33%, while the budding method failed to establish colonies.

These findings emphasize that colony division is not simply the physical separation of bees and brood. A viable mechanism for queen establishment is a major determinant of daughter-colony success.

6. In-vitro queen rearing

In-vitro queen rearing is one of the most promising developments in *T. iridipennis* propagation. Its major advantage is the possibility of producing queens without depending entirely on naturally produced queen cells within colonies. Kumar and Khan developed an in-vitro queen-rearing protocol for *T. iridipennis*. The study demonstrated that queens could be produced under controlled conditions and that the resulting queens were morphologically comparable to natural queens. The reproductive performance of the in-vitro queens further supported the protocol. The authors suggested that this technology could accelerate colony multiplication and facilitate large-scale adoption of stingless-bee management. Earlier Indian research also investigated mass multiplication of *T. iridipennis* queens, indicating the continuing development of queen-production technologies. The combination of in-vitro queen production and artificial colony division could eventually provide a more predictable system for commercial colony multiplication.

7. Mating and daughter-colony establishment

Queen production does not end with gyne emergence. A newly emerged gyne must mature, mate successfully and establish egg laying. Availability of males and suitable mating conditions are therefore essential. The TNAU study on colony propagation specifically examined the placement of divided colonies in relation to drone congregation sites, highlighting the

importance of mating ecology in daughter-colony establishment. A successful daughter colony should therefore be evaluated on the basis of queen emergence, mating, onset of egg laying, brood development, worker population and food storage rather than simply survival after division.

8. Scope for commercial meliponiculture

Systematic queen rearing and colony division could considerably increase the availability of *T. iridipennis* colonies for several applications.

8.1 Pollination

Stingless bees are increasingly recognized as useful pollinators of horticultural crops and crops grown under protected conditions. Their small body size, foraging behaviour and absence of a functional sting make them particularly attractive for greenhouse and polyhouse pollination. Large-scale availability of standardized colonies would permit development of commercial stingless-bee pollination services for vegetables, fruits and seed-production crops.

8.2 Rural entrepreneurship

Queen and colony multiplication could provide income opportunities for farmers, rural youth, self-help groups and small entrepreneurs. Potential enterprises include:

- Starter-colony production
- Established-colony production
- Queen and gyne production
- Pollination colonies
- Hive manufacturing
- Training and consultancy and
- Honey and other hive-product processing

Agricultural universities, KVKs and farmer groups could function as training and demonstration centres.

9. Conservation significance

Artificial multiplication can reduce dependence on destructive collection of natural colonies. Strong managed colonies can be used as breeder colonies to produce daughter colonies, allowing colony numbers to increase without continuously removing colonies from the wild. Non-destructive colony acquisition and eduction methods can further support conservation-oriented meliponiculture. At the same time, genetic diversity should be maintained by using

multiple breeder colonies rather than repeatedly multiplying colonies from a narrow genetic base.

10. Constraints

Important limitations to large-scale queen production and colony division include:

1. **Slow establishment:** Daughter colonies may require several weeks to become fully established.
2. **Variable queen production:** Natural queen production depends on colony and environmental conditions.
3. **Mating uncertainty:** Successful mating of gynes is essential for long-term colony establishment.
4. **Natural enemies:** Ants, resin bees and pollen mites can cause failure of divided colonies.
5. **Lack of standardization:** Brood quantity, worker-to-brood ratio, queen-cell age and colony strength require standardized criteria.
6. **Genetic management:** Commercial propagation should maintain adequate genetic diversity.

11. Future research priorities

Future research should focus on developing a standardized queen-rearing and colony-multiplication package for *T. iridipennis*. Priority areas include:

- Optimization of larval age and nutrition
- Standardization of in-vitro queen-rearing conditions
- Artificial queen-cell development
- Assessment of queen quality and mating success
- Managed mating stations
- Selection of superior breeder colonies
- Genetic characterization of breeding stocks
- Standardization of colony-division methods
- Pest and enemy management and
- Economic evaluation of queen and colony production.

The use of transparent observation hives, temperature and humidity sensors and digital colony monitoring could further improve understanding of queen development and daughter-colony establishment.

Conclusion

Queen production and colony division are important technologies for expanding *T. iridipennis* meliponiculture. Early work at TNAU demonstrated successful propagation through division of strong colonies containing natural queen cells, although establishment varied and natural enemies caused some failures. Subsequent research demonstrated that emergency queen cells could be induced in divided colonies without waiting for naturally produced queen cells. More recent research showed particularly high success when gynes or queen cells were included during artificial colony division. The development of in-vitro queen rearing represents a further technological advance by providing the possibility of producing queens independently of natural queen-cell availability.

The future scope of *T. iridipennis* therefore extends beyond traditional hive-product production to **queen production, commercial colony multiplication, protected-crop pollination, conservation and rural entrepreneurship**. Development of standardized and economically viable queen-rearing and colony-division technologies could provide a strong foundation for sustainable large-scale meliponiculture in India.

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Volume: 06 Issue No: 10

HOST IMMUNE RESPONSE AGAINST KOI HERPESVIRUS IN CARP

Article ID: AG-VO6-I10-35

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Abstract

Koi herpesvirus (KHV) or Cyprinid herpesvirus-3 (CyHV-3) has been identified as one of the most important viruses affecting common carp and koi carp globally. This disease is characterized by gill necrosis, skin ulcerations, depression, difficulty breathing, and high mortality rates. Immune response is very important for the inhibition of KHV infection and increasing the survival rate in fish. Innate and adaptive immune systems get activated in response to virus infections. Pattern recognition receptors such as Toll-like receptors detect virus particles and initiate signaling cascades against the virus. Important immune factors such as interferons, interleukins, macrophages, neutrophils, and leukocytes play a vital role in the development of defense mechanisms against virus infections. It has been reported that resistant strains of carp display increased immune modulation, enhanced chemokine activity, phagocytosis activity, and antiviral responses than susceptible strains. Mucosal immunity in skin and gills is important for the reduction of virus replication and spread. Recent transcriptomic analyses revealed the involvement of oxidative stress pathway and inflammatory pathways in addition to immune related gene modulation in infected carp. Natural products like curcumin have been found effective as an antiviral and immune modulator against KHV infection.Understanding host

immune mechanisms against KHV is important for developing effective disease management strategies, selective breeding programs, and therapeutic approaches for sustainable carp aquaculture.

Keywords

Koi herpesvirus, CyHV-3, immune response, common carp, mucosal immunity, antiviral defense

Introduction

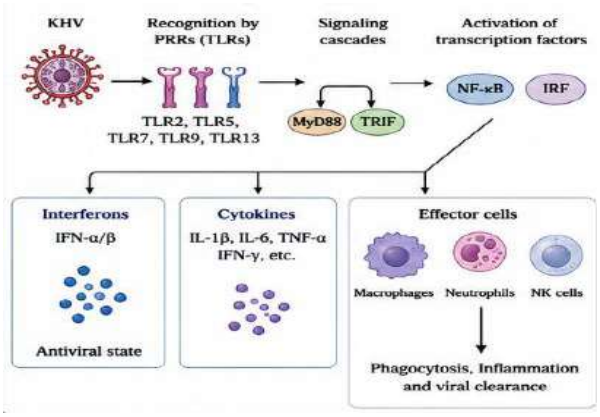
Koi herpesvirus (KHV) or Cyprinid herpesvirus-3 (CyHV-3) is a highly contagious disease affecting the common carp and koi carp around the world (Cano et al., 2024). The virus causes economic losses due to its mortality rate and rapid spread among fish populations (Tadmor-Levi et al., 2019). Koi herpes virus belongs to the order Alloherpesviridae, and the virus has a vast double-stranded viral genome with numerous open reading frames responsible for reproduction and evading the immune system of the fish (Cano et al., 2024). This virus targets epithelial cells of the fish including skin and gills and spreads throughout the body using the bloodstream (Cano et al., 2020). Symptoms of the virus include lethargy, increased mucous production, loss of appetite, difficulty breathing, skin lesions, and gill necrosis (Ji et al., 2025). High mortality is caused by the virus when the temperature ranges from 16°C and 25°C, especially 22-24°C (Cano et al., 2020).

The immunity of the carp plays a key role in limiting the replication of the virus as well as minimizing infections in the fish. The activation of the innate and acquired immunity takes place in infected fish (Hwang et al., 2017). Innate immunity involves the involvement of leukocytes, macrophages, neutrophils, cytokines, and interferon. Acquired immunity entails the formation of humoral and cell-mediated immunities (Cano et al., 2020). Recent studies on the molecular and transcriptomic aspects of host-pathogen interactions in fish infected with KHV have shown that the resistance is associated with different expressions of genes in fish (Tadmor-Levi et al., 2019). Similarly, in the investigations of fish leukocytes responses in blood during infections, it was determined that Toll-like receptor activation, oxidant activity, inflammation, and macrophage polarization take place in infected fish (Cano et al., 2024)..

Innate Immune Response Against KHV

The innate immune response can be defined as a type of immune reaction that is initiated soon after the infection by KHV. Initially, the virus infects epithelial tissues of skin and gills. After the recognition by pattern-recognition receptors, immune reaction starts (Cano et al.,

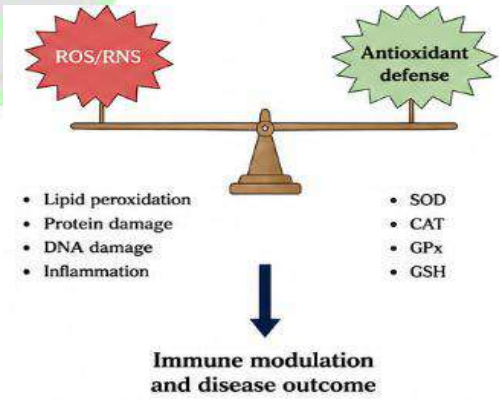
2024). Moreover, toll-like receptors (TLR2, TLR5, TLR7, TLR9, and TLR13) play an important role in viral recognition and antiviral immunity (Hwang et al., 2017; Cano et al., 2024). Antiviral interferons belong to important cytokines at this stage of infection. These types of interferons induce antiviral condition in infected and surrounding cells and thereby decrease further replication of viruses (Hwang et al., 2017). Higher levels of IFN-αβ were found in resistant carp hybrid fish compared to susceptible koi fish (Hwang et al., 2017).



Leukocytes and macrophages also perform an essential role in the infection. Gene regulation of macrophages, enhanced phagocytic activity, and involvement in inflammatory processes in leukocytes were described in transcriptome analysis (Cano et al., 2024). Macrophages help eliminate infected cells and regulate inflammatory reactions. Another vital cell of innate immunity is neutrophil. Fish that resist infections showed increased expression of cxcl8/il8 chemokine and increased recruitment of neutrophils to the site of infection (Tadmor-Levi et al.,2019)

Oxidative Stress and Immune Regulation

The process of oxidative stress occurs due to an increase in the amount of ROS and RNS generated due to KHV infection and leads to protein, lipid, and DNA damage (Ji et al., 2025). The activation of Nrf2 leads to the expression of antioxidant enzymes such as SOD, CAT, GSH-Px, and HO-1, responsible for the removal of oxidative stress (Ji et al., 2025). The regulation of antioxidant response and immunity takes place through the Nrf2-Keap1/ARE pathway (Ji et al., 2025). Inflammation associated with KHV mainly activates the NF-κB pathway (Ji et al., 2025). This pathway activation leads to the secretion of mediators of inflammation, IL-6 and TNF-α. The excessive stimulation of this pathway can cause severe inflammation of gills and skin. According to the recent studies, the use of curcumin in the treatment of KHV infection was proved to be effective (Ji et al., 2025). It stimulated the



activity of antioxidant enzymes while reducing the amount of oxidative and inflammatory indicators (Ji et al., 2025). Moreover, it suppressed the expression of inflammatory genes regulated by NF-κB while increasing the rate of survival in fish (Ji et al., 2025).

Adaptive Immune Response

Adaptive immunity follows primary innate immunity and provides life-long protection against KHV. In adaptive immunity, B lymphocytes and antibodies take part. The presence of seroconversion results in the development of anti-KHV antibodies that help in neutralization of the virus. Studies of mucosal immunity have found IgM and IgZ2 to be very significant for mucosa of the skin protection from KHV infection (Cano et al., 2020). First, KHV inhibits the activities of complement proteins and mucosal immunity components. This inhibition helps the virus to persistently shed through skin mucus for several weeks. The subsequent production of antibodies assists in the elimination of the virus from the mucosa (Cano et al., 2020).

Another form of resistance against the infection provided by the immune system is cell-mediated immunity. Cytotoxic T cells make a substantial contribution to eliminating infected cells. However, studies by other scholars indicated the inhibition of T-cell markers in latent infections (Cano et al., 2024). KHV causes latency of the virus lifelong in leukocytes and neurological tissues. This allows the virus to reproduce under stress such as changes in temperatures (Cano et al., 2020).

Resistant and Susceptible Carp Responses

0However, there is substantial variation in the immune responses and resistance of different carp populations towards KHV infection. Unlike susceptible carp, resistant carp possessed low levels of virus replication, minimal tissue damage, and had high survival rates (Tadmor-Levi et al., 2019). From the transcriptome analysis, it was established that the susceptible fish exhibited an elevated yet less efficient antiviral immune reaction, marked by heightened expression of interferon and inflammatory response genes (Tadmor-Levi et al., 2019). However, resistant fish had a more controlled immune response, and they exhibited a high responsiveness of their neutrophils. This is due to the upregulation of chemokines, responsible for attracting neutrophils, in resistant carp (Tadmor-Levi et al., 2019). According to histological analysis, there was reduced tissue necrosis and viral protein expression in resistant hybrid carp when compared to the susceptible koi carp (Hwang et al., 2017).

Mucosal Immunity and Viral Shedding

Skin mucus acts as an important defense mechanism against KHV infection. Immune components such as lysozyme, complement factors, antimicrobial peptides, and immunoglobulin act to inhibit replication (Cano et al., 2020). During KHSV infection, there is an impairment of the immune system as a result of the downregulation of the production of complement factors and immunoglobulin (Cano et al., 2020). This leads to immune modulation and results in increased viral shedding, giving more opportunities for viral spread. The shedding of the virus could continue for several weeks based on the optimum temperature environment that is provided. Temperature plays a crucial role in the manifestation of the infection caused by KHV. The infection develops faster in fishes exposed to optimum temperatures (Cano et al., 2020).

Conclusion

Immune systems of the host fish are crucial for managing the infection caused by the KHV in the fish species. Innate immunity, which is induced by Toll-like receptors, interferons, macrophages, neutrophils, and inflammatory cytokines, is the first barrier in preventing the infection of KHV. Another form of protection from the infection in carp comes from antiviral immunity as well as mucosal immunity that involves production of antibodies. Carps, which are resistant to the infection, have efficient immune regulations and antiviral mechanisms. Among the biological pathways involved in the process are oxidative stress and inflammation signaling pathway. Studies done recently on the topics of transcriptomics and immunology have greatly contributed in understanding virus-host interactions. Some natural immunomodulators such as curcumin can help fight the infection.

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Volume: 06 Issue No: 10

ADVANCES IN WHEAT SEED PRODUCTION TECHNOLOGY IN THE PENINSULAR ZONE OF INDIA

Article ID: AG-VO6-I10-36

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Abstract

Considering the climatic and geographical conditions of different wheat-growing zones, the ICAR–Indian Institute of Wheat and Barley Research (IIWBR), Karnal, in collaboration with various agricultural universities, develops and releases suitable wheat varieties to ensure the availability of quality seeds for farmers. Farmers can also produce quality seeds on their own farms by selecting improved varieties and adopting recommended cultivation practices appropriate to their specific sowing conditions.

Introduction

Wheat is one of the most important cereal crops in India and thrives under cool and dry climatic conditions. It is predominantly cultivated in Punjab, Haryana, Rajasthan, Uttar Pradesh, Madhya Pradesh, Bihar, West Bengal, Uttarakhand, Himachal Pradesh, Karnataka, and Maharashtra. Based on climatic conditions, the wheat-growing regions of India are classified into five major zones: the North-Western Plains Zone, North-Eastern Plains Zone, Northern Hills Zone, Central Zone, and Peninsular Zone. During 2025–26, wheat was cultivated over an area of 33.60 million hectares in India, producing 120.66 million tonnes with an average productivity of 35.91 quintals per hectare (ICAR–IIWBR, 2026).

The Peninsular Zone comprises Maharashtra, Andhra Pradesh, Karnataka, Goa, and Tamil Nadu, excluding the Nilgiris and Palani Hills. The major wheat types cultivated in this region include sarbati wheat (Triticum aestivum), bansi wheat (Triticum durum), and khapli

wheat (Triticum dicoccum), which are well suited to the prevailing climatic conditions. However, wheat cultivation in this zone is frequently affected by high temperatures, particularly during the stem elongation and flowering stages. Therefore, the cultivation of short-duration and heat-tolerant varieties is essential for ensuring stable wheat production under these conditions.

Although wheat productivity in the Peninsular Zone is comparatively lower than that in the North-Western Plains, particularly Punjab and Haryana, wheat produced in the Central and Peninsular Zones is considered to possess superior quality and considerable export potential. Furthermore, Karnal bunt, a seed-borne disease of wheat, is less prevalent in this region, which further enhances the potential market value of wheat produced in these zones.

Wheat Species Cultivated in India

A) Sarbati Wheat (*Triticum aestivum*)

Best suited for chapatis, breads, biscuits, and cookies due to its strong gluten and high protein content. Suitable regions include Madhya Pradesh, Gujarat, Maharashtra, and parts of southern Rajasthan. Many improved varieties resistant to rust and high-yielding are available.

B) Durum/Bansi Wheat (*Triticum durum*)

Well adapted to hot and dry conditions in Madhya Pradesh, Gujarat, Maharashtra, Karnataka, and parts of Rajasthan. Known for high protein and golden-colored grains, it is widely used for making suji/rava, pasta, macaroni, and noodles due to its strong gluten.

C) Emmer/Khapli Wheat (*Triticum dicoccum*)

Recognized for long, narrow grains with high protein (11.8–15.3%), carbohydrates (78.7–83.2%), and dietary fiber (>16%). Popular for traditional foods such as rava, kheer, and breakfast items. With its low glycemic index, it is particularly beneficial for diabetic patients.

Standard Practices for Quality Seed Production

New wheat varieties are first released as breeder seeds by ICAR institutes or agricultural universities. These are then multiplied into foundation and certified seeds by organizations such as the National Seed Corporation and Mahabeej. It generally takes three to four years for seeds of a new variety to reach farmers. Once available, farmers can continue seed production on their fields or partner with seed companies for certified seed production. Being self-pollinated, wheat allows farmers to reuse their own seed for two to three years, provided proper precautions and storage methods are followed.

Table 1 Recommended wheat varieties for Peninsular Zone as per sowing conditions

Sowing Condition	Period of sowing	Species	Name of the variety	Year of release	Productivity (q/ha)	Days to maturity
Rainfed Condition	15 to 31 October	*Triticum aestivum* (Sarbati)	Netravati (NIAW 1415)	2010	19.0	105
			Vimal (AKAW 3722)	2014	42.0	107
			UAS 347	2015	18.0	96
			UAS 375	2018	21.4	103
		Triticum durum (Bansi)	MACS 4028	2018	20.3	103
			Panchvati (NIDW 15)	2022	15.0	105
Timely Sown Restricted Irrigation condition (Max 2 irrigations)	25 October to 5 November	*Triticum aestivum* (Sarbati)	Pusa Ujala (HI 1605)	2017	30.0	105
			Phule Satwik (NIAW 3170)	2020	33.7	107
			Phule Anupam (NIAW 3624)	2022	32.5	107
			Phule Anurag (NIAW 4028)	2024	35.5	105
			Phule Sampanna (NIAW 4267)	2025	35.0	105
			HI 8802	2020	29.5	106
			HI 8805	2020	30.9	100
			MACS 4058	2020	29.0	105
		Triticum durum (Bansi)	NIDW 1149	2021	26.0	103

Timely Sown Irrigation condition	5 to 15 November	*Triticum aestivum* (Sarbati)	UAS 304	2013	46.0	110
			MACS 6222	2014	50.0	110
			Phule Samadhan (NIAW 1994)	2016	46.1	115
			MACS 6478	2016	45.0	107
			DBW 168	2018	48.8	112
		Triticum durum (Bansi)	MACS 3949	2017	44.0	111
			DDW 48	2020	44.0	110
		Triticum dicoccum (Khapli)	MACS 2971	2009	50.2	107
			HW 1098	2013	45.5	110
Late Sown Irrigation condition	15 November to 15 December	*Triticum aestivum* (Sarbati)	MACS 6222	2014	50.0	110
			Pusa Amulya (HD 3090)	2014	42.1	101
			Phule Samadhan (NIAW 1994)	2016	44.3	110
			PDKV Sardar	2016	39.2	108
			Pusa Wani (HI 1633)	2021	41.7	100
			Phule Shashwat (NIAW 4114)	2025	45.6	104

Quality Standards for Wheat Export

- Moisture content: below 12.0%
- Admixture: below 0.70%
- Protein content: above 12.0%
- Broken/over-dried grains: below 4.0%

- Damaged grains: below 2.0%
- Grain damage: below 1.0%
- Wet gluten: above 25.0%
- Falling number: above 300 seconds
- Hectoliter weight: above 78.0 kg/hl

(Source: Haryana State Co-operative Supply and Marketing Federation Ltd.)

Seed Production Guidelines

- **Variety selection**: Improved seeds can boost yield by 15–20% (**Table 1**).
- **Source of seed**: Always use foundation or certified seed from reliable agencies (ICAR, SAU, State Seed Corporations, or recognized seed companies). Keep seed labels/tags.
- **Seed treatment**: Treat seeds with Carbendazim (1.25 g/kg) or Tebuconazole (1.0 g/kg) to prevent seed-borne diseases.
- **Isolation distance**: Maintain 3 m (up to 150 m if Smut is prevalent).
- **Roguing**: Remove off-types, diseased plants, or those differing in leaf/stem traits to ensure genetic purity.
- **Irrigation**: Provide 4–5 irrigations in medium to heavy soils at key stages—CRI (18–21 DAS), boot stage (40–45 DAS), flowering/milking (60–65 DAS), and grain filling (80–85 DAS).
- **Weed control**:
  - Pre-emergence: Pendimethalin (1250 ml/acre).
  - 30–35 DAS: Isoproturon (500 g/acre) or 2,4-D (500 ml/acre).
- **Fertilizer management**:
  - Timely sown: 58:24:16 kg N:P:K/acre (DAP, Urea, MOP).
  - Late sown: 52 kg DAP, 26 kg MOP + urea split across irrigations.
- **Crop protection**:
  - Rust: Spray Propiconazole (0.1%) + Copper Oxychloride (0.2%).
  - Blight: Spray Copper Oxychloride (0.2%) + Mancozeb (0.2%).
  - Aphids: Spray Imidacloprid (40 ml/acre).
  - Stem borer: Spray Quinalphos (300 ml/acre).
- **Harvesting & threshing**: Prevent mixing of seeds; ensure machines are cleaned.
- **Seed processing**: Pre-cleaning, grading, and separation of light/broken seeds (10–12%).

- **Seed testing**: Ensure ≥85% germination and ≥98% physical purity before certification.
- **Storage**: Store in dry, ventilated areas with 10–12% moisture; use new bags and wooden pallets to prevent contamination or moisture absorption.

Conclusion

Farmers can successfully produce quality wheat seeds on their own farms by cultivating improved varieties adapted to local conditions and following recommended seed production practices. When properly processed and stored under suitable conditions, these seeds can be reused for two to three years, thereby promoting sustainable seed production and enhancing farm profitability.

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Volume: 06 Issue No: 10

STRATEGIES FOR SUSTAINABLE WHEAT PRODUCTION UNDER HEAT AND DROUGHT STRESS IN MAHARASHTRA STATE

Article ID: AG-V06-I10-37

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Abstract

Wheat (*Triticum aestivum* L.) productivity in Maharashtra is increasingly threatened by terminal heat stress, inadequate soil moisture, and irregular rainfall. These stresses adversely affect crop growth, grain filling, and final yield, particularly under rainfed and limited-irrigation conditions. Sustainable wheat production requires an integrated approach involving heat- and drought-tolerant varieties, timely sowing, efficient irrigation, soil moisture conservation, balanced nutrient management, and effective weed control. Conservation agriculture, crop residue management, and improved soil health practices can further enhance resource-use efficiency. Wheat breeding programmes also play a vital role in identifying and developing stress-tolerant genotypes. This article reviews the major challenges posed by heat and drought stress in Maharashtra and discusses practical management strategies to improve wheat productivity and production stability under changing climatic conditions.

Introduction

Wheat (Triticum aestivum L.) is a major cereal crop essential for global food and nutritional security. However, heat and drought stress adversely affect its growth, grain filling, yield, and quality, particularly under rainfed and limited-irrigation conditions. In Maharashtra, wheat occupied approximately 15.27 lakh hectares during 2025–26, producing 35.09 lakh tonnes with an average productivity of 2,298 kg/ha. Limited irrigation, inadequate soil moisture, and rising temperatures during reproductive and grain-filling stages are major constraints to wheat

productivity in the state. Sustainable production requires an integrated approach involving heat- and drought-tolerant varieties, timely sowing, efficient irrigation, soil-moisture conservation, balanced nutrient management, and effective weed control. Wheat breeding programmes also play a vital role in developing high-yielding, stress-tolerant genotypes suited to local agro climatic conditions. This article reviews the effects of heat and drought stress on wheat and discusses practical management strategies to improve productivity, resource-use efficiency, and production stability under changing climatic conditions.

Major reasons for low wheat productivity in Maharashtra

1. **Higher temperature during grain filling**
    - Maharashtra has a relatively warmer winter than the major wheat-growing states of North India.
    - High temperature during anthesis and grain filling accelerates crop maturity, shortens the grain-filling period and reduces **1000-grain weight and grain yield**.
    - This is particularly important under late-sown conditions.
2. **Large area under late sowing**
    - Wheat is often sown late after harvesting of preceding crops such as soybean, cotton, sugarcane and other kharif crops.
    - Late sowing exposes the crop to progressively increasing temperatures during reproductive and grain-filling stages.
    - Timely sowing is therefore one of the most important factors for improving productivity.
3. **Limited and uncertain irrigation**
    - A considerable proportion of wheat in Maharashtra is grown under restricted irrigation or limited soil moisture.
    - Wheat requires adequate moisture particularly at CRI, flowering and grain-filling stages.
    - Inadequate irrigation during these critical stages substantially reduces yield.
4. **Water stress and terminal drought**
    - In several parts of Maharashtra, available irrigation water declines toward the end of the season.
    - Consequently, the crop may experience moisture stress during grain filling, resulting in poor grain development.

5. **Predominance of relatively short winter duration**
    - Compared with northern wheat-growing regions, Maharashtra generally has a shorter period of cool temperatures.
    - Wheat therefore has less opportunity to accumulate biomass and assimilates before maturity.
6. **Lower adoption of improved agronomic practices**
    - Productivity is affected by non-optimal:
        - Seed rate and planting geometry,
        - Fertilizer application,
        - Nitrogen management,
        - Irrigation scheduling,
        - Weed management,
        - Seed treatment, and
        - Disease and pest management.
7. **Imbalanced nutrient management**
    - Farmers often emphasize nitrogen application while phosphorus, potassium, sulphur and micronutrients, particularly zinc, may receive inadequate attention.
    - Declining soil fertility and micronutrient deficiencies can limit yield potential.
8. **Varietal mismatch with production environments**
    - Varieties developed for cooler northern environments may not always express their full yield potential under Maharashtra's warmer, late-sown and restricted-irrigation conditions.
    - There is a need for varieties specifically adapted to:
        - Timely-sown irrigated conditions,
        - Late-sown irrigated conditions,
        - Restricted irrigation,
        - Heat stress, and
        - Drought-prone environments.
9. **Heat and drought interaction**
    - In Maharashtra, heat stress and moisture stress can occur simultaneously during grain filling.

- The combined stress can be more damaging than either stress alone, affecting photosynthesis, chlorophyll retention, grain number and grain weight.

11. **Disease and pest pressure**
    - Diseases such as leaf rust, stripe rust, powdery mildew, spot blotch and Karnal bunt, along with insect pests such as aphids, can contribute to yield losses when susceptible varieties or inadequate management are used.
    - Disease pressure varies considerably among production environments.
12. **Poor crop establishment**
    - Uneven land preparation, inadequate seedbed moisture, improper sowing depth and poor-quality seed can lead to non-uniform emergence and reduced plant population.
13. **Competition with high-value crops**
    - In irrigated areas, wheat competes with crops such as sugarcane, onion, vegetables and other remunerative crops.
    - Consequently, wheat may receive less irrigation, fertilizer and management attention in some farming systems.
14. **Environmental variability across Maharashtra**
    - Maharashtra has substantial variation in rainfall, soil type, temperature, irrigation availability and cropping systems.
    - A single production technology or variety cannot perform optimally across all these environments.

Important measures for sustainable wheat production during drought (El Niño) conditions

1) **Selection of Heat/Drought -Tolerant Varieties**

- Considering the likelihood of relatively high temperatures during critical crop growth stages, preference should be given to heat-tolerant varieties.
- Varieties capable of tolerating high temperatures, particularly during flowering and grain-filling stages, are essential.
- An integrated approach should be adopted while selecting varieties, considering **high yield potential, heat tolerance, drought tolerance, and disease resistance**. (Fig 1)

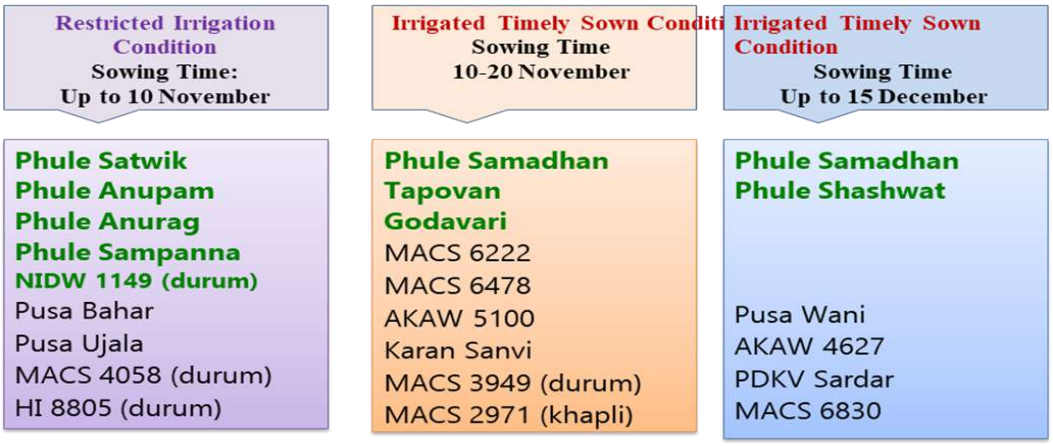


Fig 1: Selection of wheat varieties as per sowing condition

2) Priority to Timely Sowing

- As temperatures may rise under El Niño conditions, timely sowing of wheat is extremely important.
- Delayed sowing exposes the flowering and grain-filling stages to progressively higher temperatures.
- Consequently, the grain-filling period may be shortened, resulting in reduced thousand-grain weight and lower grain yield.

3) Integrated Nutrient Management

- Treat seeds with biofertilizer cultures or Phule Super Biomix.
- Apply organic manures to improve soil health and nutrient availability.
- During water stress and periods of extreme heat, spray **13:00:45 at 10 g per 10 litres of water**.
- Spray **19:19:19 at 200 g per 10 litres of water** at 55 and 70 days after sowing.
- Spray **Phule Micro Grade-II at 50 ml per 10 litres of water** at 40–45 days after sowing, followed by **100 ml per 10 litres of water** at 60–65 days after sowing.

4) Efficient Water Management

- As water availability and rainfall may become uncertain due to El Niño, every drop of water must be used efficiently.
- Plan the area to be sown and the irrigation schedule in advance, based on the availability of water.
- Avoid unnecessary or excessive irrigation and apply water according to crop requirements.

- The principle of "More Crop per Drop" will become increasingly important for wheat production.

5) Irrigation at Critical Growth Stages

- Wheat does not require the same amount of water at every growth stage. Therefore, irrigation should be prioritized during critical crop growth stages.
- In particular, water stress should be avoided during the crown root initiation (CRI), flowering, and grain-filling stages.
- When water availability is limited, irrigation should be scheduled according to the crop's most sensitive growth stages.
- Even limited irrigation applied at the right time may be more beneficial for grain yield than a larger quantity of water applied at the wrong time.

6) Moisture Conservation

- Proper management of crop residues helps reduce evaporation and conserve soil moisture.
- Adopt organic mulching and drip irrigation, wherever feasible, to conserve soil moisture and improve water-use efficiency.
- Under water-stress conditions, spray **kaolin at 5 g per litre of water** as an anti-transpirant, or **potassium silicate at 2 g per litre of water**, to help reduce moisture stress.

7) Timely Weed Management

- Under water-deficit conditions, weeds compete more intensely with wheat for water, nutrients, and sunlight. Therefore, timely and effective weed control is an important component of drought management.
- Controlling weeds during the early stages of crop growth enables wheat plants to use the available water and nutrients more efficiently. This helps maintain the yield potential of the crop even under limited water availability.

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Volume: 06 Issue No: 10

BEYOND ADVICE: REIMAGINING EXTENSION SERVICES FOR A RESILIENT HORTICULTURE SECTOR IN HIMACHAL PRADESH

Article ID: AG-VO6-I10-38

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Abstract

Horticulture has become a major source of rural income in Himachal Pradesh, but its future depends on more than expanding cultivated area or distributing technologies. Farmers must navigate climate variability, pest and disease risks, changing production costs, scheme procedures and volatile markets. This article reframes agricultural extension as a connected service system that helps growers make decisions across the entire horticultural value chain. Drawing on reported state-level trends and programme information, it examines extension through five linked functions: diagnosis, learning, risk communication, scheme navigation and market connection. The evidence points to substantial training and programme outreach, but also to uneven performance across horticultural subsectors and the limitations of judging success through attendance or beneficiary counts alone. The article proposes a shift towards problem-led, locally tailored and outcome-based extension, supported by digital tools but anchored in trusted field-level contact. It argues that extension should be evaluated by whether farmers adopt appropriate practices, reduce avoidable losses, improve market participation and become better able to manage uncertainty.

Keywords: Agricultural extension; Himachal Pradesh; horticulture; farmer advisory services; climate resilience; digital extension; market linkages; outcome-based evaluation

Introduction

Himachal Pradesh's horticulture sector has expanded considerably, from 792 hectares in 1950–51 to approximately 2,37,638 hectares in 2024–25(Economic Survey of Himachal Pradesh,

2025). Fruit production reached about 7.33 lakh tonnes in 2025, and horticulture now occupies nearly 26 per cent of the state's cultivated area. The sector's estimated contribution to agricultural production value is around ₹4,290.65 crore. Apple remains dominant, occupying approximately 1,16,338 hectares and accounting for about 77.58 per cent of fruit production (Economic survey of Himachal Pradesh, 2025-26). These figures demonstrate horticulture's economic importance, but scale is not the same as resilience. As production systems become more commercially oriented, growers must respond to changing input costs, quality standards, market expectations and increasingly uncertain weather. Production gains can be undermined by hailstorms, irregular rainfall, pests, rising costs, post-harvest losses and sudden market changes. The challenge is therefore not simply to expand horticultural output, but to help farmers make timely, informed decisions under changing economic and environmental conditions.

This is where extension services become strategically important. Their role should not be reduced to delivering training sessions or circulating technical recommendations. Farmers need help interpreting information, diagnosing problems, comparing options, navigating public schemes and connecting production decisions with market requirements. In a mountainous state with substantial variation in altitude, terrain and access to infrastructure, the same recommendation may not work equally well everywhere. Extension must therefore operate as a responsive service system: one that begins with farmers' problems, links them to suitable expertise and follows up to determine whether the advice actually helped. This broader role makes extension a potential bridge between research, public investment and farmers' everyday decisions, while providing a practical feedback channel through which local constraints can inform future programmes.

From technology transfer to a decision-support system

Traditional extension is often assessed through visible activities such as meetings, demonstrations, trainings and the number of farmers contacted. These activities matter, but they are only the beginning of the process. Information has value when a farmer can understand it, judge whether it applies locally, obtain the required inputs and use it to make a better decision. A more innovative approach would treat extension as a sequence of connected functions: identify the problem, provide context-specific advice, help the farmer act, and assess the result. This shifts attention from the volume of communication to its usefulness.

For example, a pest advisory is incomplete if it merely identifies a possible threat. Farmers may also need help confirming the diagnosis, choosing an appropriate response, understanding safe and timely application, and assessing whether the intervention worked. Similarly, advice on a new crop or variety should consider elevation, water availability, labour, expected costs, buyer demand and price risk. Extension becomes more valuable when it helps farmers weigh trade-offs rather than simply prescribing a practice. This decision-support model also creates a feedback loop through which farmers' experiences can inform future recommendations and programme design.

The extension network: coordination matters more than institutional visibility

Himachal Pradesh's extension landscape includes the Department of Horticulture, agricultural universities, Krishi Vigyan Kendras, financial institutions, marketing agencies, farmer organisations and digital platforms. These actors perform complementary functions: research and technical guidance, field demonstrations, training, financial support, market information and implementation of public schemes. The challenge is to make these services work together from the farmer's perspective. When advisory services, input support, finance and marketing operate in isolation, growers may receive fragmented information or be unable to act on recommendations.

A farmer-centred extension system would create clearer pathways between these services. Field staff should be able to refer farmers to relevant technical experts, scheme officers, laboratories, financial services or market organisations, and receive feedback on whether the problem was resolved. Local adaptation is essential because the production conditions of one valley may differ substantially from those of another. Farmers should also be treated as sources of practical evidence: their experience can reveal whether a recommendation is affordable, workable and effective under real farm conditions. Strong coordination would make extension less institution-centred and more focused on resolving the constraints that farmers actually face.

Climate and pest advisories: timely, local and actionable

Climate variability makes timely advice increasingly important for horticultural producers. Hail, irregular rainfall, water scarcity, temperature changes, pests and diseases can affect yields and quality within short periods. General advisories may be too broad to guide decisions across different elevations and local conditions. Extension services should therefore connect weather information and pest surveillance with local interpretation: what the alert means

for a particular crop, what action is feasible, when it should be taken and where further diagnosis is available.Digital tools can increase the speed and reach of advisories, but they should not replace field-level expertise. A phone message may indicate a possible disease, while confirmation may require a visit or expert assessment. Connectivity, digital literacy and access to smartphones also differ across communities. A practical model is therefore hybrid: digital platforms distribute alerts and basic guidance, while local extension workers help interpret them, verify problems and support follow-through. Climate-resilient advice should also consider the costs and feasibility of measures such as micro-irrigation, anti-hail protection, crop diversification and improved crop management.

Schemes and services: helping farmers move from eligibility to outcomes

Public programmes support planting material, irrigation, machinery, post-harvest infrastructure and other horticultural needs. The Mission for Integrated Development of Horticulture, the Rashtriya Krishi Vikas Yojana, the Pradhan Mantri Krishi Sinchayee Yojana and the Sub-Mission on Agricultural Mechanization are among the schemes identified in the source material. The cumulative number of farmers covered under MIDH increased from 2,60,421 in 2020–21 to 2,77,028 in 2025–26. Under PMKSY, a reported allocation of ₹14.87 crore in 2025–26 had benefited 650 farmers and covered approximately 385 hectares up to 31 December 2025(Economic Survey of Himachal Pradesh,2025).

However, a scheme's announcement or allocation does not guarantee that farmers can access and use the support. Information may not reach every eligible grower; procedures may be difficult to navigate; and farmers may lack the funds or technical support needed to complete an investment. Extension can act as a bridge by explaining eligibility, assisting with applications, clarifying technical requirements and reporting recurring barriers to implementing agencies. The performance of schemes should be assessed across the full chainfrom allocation and delivery to actual adoption and sustained farm-level benefits.

The reported gap between allocations and expenditure further underlines the need for careful monitoring. For example, ₹11 crore was allocated under the Himachal Pushp Kranti Yojana in 2021–22, while reported expenditure was ₹1.8 crore. Under the Himachal Khumb Vikas Yojana, ₹5 crore was allocated in the same year and expenditure was approximately ₹65.85 lakh(Economic Survey of Himachal Pradesh,2021). Some figures were reported only up to 31 December of the relevant budget year, so they cannot by themselves establish programme

failure. They do, however, justify investigating whether information gaps, administrative delays or access barriers prevented intended support from reaching farmers in time.

Extension must connect production with markets

Horticultural development creates lasting economic value only when production is converted into saleable quality and reliable income. Perishable fruits and vegetables require timely harvesting, grading, packaging, storage, transport and access to buyers. HPMC supports horticultural marketing and processing, while the State Agricultural Marketing Board provides market information, promotes grading and standardisation, and supports e-NAM and market infrastructure. Farmer Producer Organisations can help growers aggregate produce, access inputs and credit, and strengthen bargaining power. Around 149 NABARD-supported FPOs were reported in Himachal Pradesh as of 2025, involving approximately 36,500 farmer members.

Extension services should therefore help farmers understand more than production techniques. They can communicate market arrivals and price information, explain quality standards, support collective marketing and link growers with post-harvest and value-addition options. This is especially important where individual farmers have limited volumes or weak bargaining power. Production advice that ignores buyers, costs and post-harvest constraints risks increasing output without improving net returns. Integrating market intelligence into extension can help farmers make better-informed choices about crop planning, harvest timing and sale channels.

Diversification as a managed transition

Diversification can broaden rural income sources and reduce dependence on a single crop, but it should not be promoted as a universal solution. Its suitability depends on local climate, skills, investment, labour, infrastructure and market demand. Reported initiatives in Himachal Pradesh include mushroom cultivation, commercial floriculture and beekeeping. Under the Himachal Khumb Vikas Yojana, approximately 500.58 tonnes of compost were distributed in 2024–25 and mushroom production reached around 3,963.96 tonnes. Commercial flower cultivation covered about 234.17 hectares in 2024–25, while honey production was reported at approximately 2,330.79 tonnes(Economic Survey of Himachal Pradesh,2025).

The HP Subtropical Horticulture, Irrigation and Value Addition project, with an estimated investment of ₹1,292–1,300 crore, aims to develop 6,000 hectares of climate-resilient subtropical horticulture across 400 clusters in 28 development blocks covering seven districts. It

includes 162 irrigation schemes and targets approximately 15,000 farm households(Department of Horticulture,Himachal Pradesh 2025). Such investment can expand opportunities, but infrastructure alone cannot ensure viable outcomes. Extension should help farmers assess crop suitability, operating costs, maintenance needs, production risks and buyer access before and after adoption. The objective should be informed diversification, not simply a larger number of crops or beneficiaries.

Uneven subsector trends demand targeted extension

The reported data show that recent performance varies across horticultural subsectors. Between 2020–21 and 2024–25, fruit area increased from 234.79 thousand hectares to 236.96 thousand hectares, while production rose from 624.49 thousand tonnes to 648.30 thousand tonnes. The reported compound annual growth rates were 0.23 per cent for area, 0.93 per cent for production and 0.70 per cent for productivity. By contrast, vegetable area declined from 91.80 thousand hectares to 88.78 thousand hectares, while production fell from 1,875.26 thousand tonnes to 1,679.55 thousand tonnes. Productivity decreased from about 20.43 to 18.92 tonnes per hectare(Department of Agriculture & Farmers Welfare).

For vegetables, the reported annual growth rates were −0.83 per cent for area, 2.70 per cent for production and 1.90 per cent for productivity. Floriculture also declined: flower area fell from 0.36 to 0.29 thousand hectares and production from 11.75 to 8.53 thousand tonnes. Reported growth rates were 5.20 per cent for area, 7.67 per cent for production and 2.50 per cent for productivity. These figures identify where attention is needed, but they do not explain the causes. Extension services should investigate whether the declines are associated with input costs, weather, pests, labour, crop choices or marketing constraints before prescribing solutions. Crop- and location-specific diagnosis is more defensible than a uniform response across the state.

A new way to measure extension success

The central innovation required is a shift from activity-based reporting to outcome-based accountability. Counts of trainings, advisories, demonstrations and beneficiaries describe the volume of work, but not its effectiveness. A stronger evaluation framework would track whether farmers received relevant advice, understood it, adopted appropriate practice, overcame implementation barriers and achieved a measurable result. Outcomes might include reduced avoidable losses, improved quality, more efficient input use, stronger market participation or greater capacity to respond to climate risks.

Evaluation should also include farmer feedback and examine differences across locations and farm types. A practice may be effective but unaffordable for smaller growers; a digital service may reach some communities but miss others; and a subsidy may be delivered without the complementary advice needed to use the equipment. Learning from these differences would help extension institutions adapt their services and public programmes. The ultimate objective is not to demonstrate that extension activity took place, but to establish whether the service solved a relevant problem and whether the benefit can be sustained.

Conclusion

Himachal Pradesh's horticultural transformation has created important economic opportunities, but the next stage will be shaped by climate risks, production constraints and market uncertainty. The sector needs extension services that connect technical knowledge with practical decisions, public support, risk management and market access. Digital tools can widen reach, but trusted local expertise remains essential for diagnosis and follow-up. Training should be judged by changes in practice, schemes by the benefits farmers realise, and advisories by their usefulness under local conditions. Reimagined in this way, extension becomes more than a channel for information: it becomes the connective infrastructure through which horticultural research, public investment and farmer experience can produce more resilient and inclusive livelihoods.

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Volume: 06 Issue No: 10

CAN AI HELP US BREED BETTER FARM ANIMALS?: HOW ARTIFICIAL INTELLIGENCE IS CHANGING THE WAY WE SELECT AND BREED LIVESTOCK AND POULTRY

Article ID: AG-VO6-I10-39

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Introduction

Every person who keeps animals has probably wondered what their young ones will be like. Will the calf grow into a good milk-producing cow? Will the lambs grow well and remain healthy? Will the chicks survive and thrive through the cold months? For generations, farmers have relied on their experience and careful selection of animals to improve the next generation, although some uncertainty has always remained.

Over time, scientific advances have helped make animal breeding more systematic. Today, artificial intelligence (AI) is opening up new possibilities in this field. By analyzing information on an animal's genetic makeup, growth, health and production, AI can help breeders identify animals with desirable traits. But how useful is this technology in practice? Can it really help us breed better cattle, sheep, goats, pigs and poultry? Let us explore how AI is becoming part of modern animal breeding and what it could mean for the future.

Breeding, then and now

Animal breeding is one of humankind's oldest practices. Long before anyone had heard of genes, early farmers selected the gentlest, fastest-growing or best-milking animals and mated them to produce offspring with desirable traits. Over many generations, selective breeding transformed the ancestors of domesticated animals into the diverse breeds of cattle, sheep, goats, pigs and poultry we know today.

The twentieth century brought major scientific advances. Breeders began keeping careful records of pedigrees, milk yields and growth rates, and using statistical methods to estimate how much of the variation in an animal's performance was due to genetic differences. Artificial

insemination allowed a single outstanding bull to sire many thousands of calves, sometimes across different countries (Lonergan, 2018). These developments helped accelerate genetic improvement.

Then came the DNA era. In 2001, Meuwissen and colleagues proposed a method for predicting an animal's genetic merit using information from markers distributed across its genome. This work laid the foundation for what is now known as genomic selection (Meuwissen et al., 2001). Instead of waiting years to see how a young bull's daughters perform, breeders could increasingly estimate his genetic merit at a much younger age using genomic information.

Even so, animal breeding takes time. A cow has one calf at a time, and the effects of a breeding decision can influence a herd for several generations. Managing this complexity requires breeders to consider many traits and large amounts of information—an area where artificial intelligence may prove useful.

Why does all this matter? Livestock products such as milk, eggs and meat feed billions of people and support the livelihoods of millions of farming families. Choosing the right parents is one of the important ways to improve the productivity and health of farm animals. Because genetic improvements can be passed from parents to offspring, their benefits can continue across generations.

So, what exactly is AI?

When people talk about AI in farming, they often mean machine learning, a branch of AI that allows computers to learn patterns from data. Think about how a child learns to recognize a mango. Nobody hands the child a rulebook. The child sees many mangoes—ripe and unripe, big and small—and gradually learns to recognize them. Machine learning works in a similar way: a computer is trained using many examples to identify patterns and make predictions.

Modern livestock farms and breeding programmes produce an astonishing amount of information: DNA profiles, daily milk records, feed intake, body weights, photographs, videos, temperature readings and health histories. It can be difficult for people to analyze all these data and identify complex relationships among different factors. Machine learning can help by analyzing large datasets and identifying patterns that might otherwise go unnoticed (Morota et al., 2018).

One point is worth stressing. AI does not replace biology. An animal's traits are influenced by its genes, nutrition, management and environment, often through interactions

among them. AI simply helps us analyze the available evidence and make better-informed decisions.

Four ways AI is already at work

Reading the genome—Genomic predictions have traditionally relied on statistical models. Machine learning methods are now being tested alongside them, particularly for traits influenced by complex genetic relationships. Although these methods can identify useful patterns in large genomic datasets, they do not consistently outperform conventional approaches. Their usefulness depends on the traits being studied, the data available and the prediction method used (Chafai et al., 2023).

Watching animals without disturbing them—Measuring things like body condition, gait or feeding behaviour has traditionally required direct observation and manual recording. Now cameras, sensors and wearable tags can collect this information continuously or at frequent intervals, and AI can analyze these data to estimate animal traits and behaviour. Berckmans (2017) describes precision livestock farming as an approach that uses continuous monitoring and data analysis to support more precise livestock management. For breeders, this means the potential to collect more detailed information on traits that were previously difficult, time-consuming or expensive to measure on a large scale.

Spotting health and fertility problems early—Wearable sensors can track an animal's movement, temperature and chewing activity, while algorithms can identify patterns associated with its normal behaviour. When these patterns change, the system can raise an alert: perhaps a cow is limping, approaching estrous, or showing signs of illness. AI-based methods for detecting lameness in dairy cattle have shown promise, although further validation is needed before their performance can be generalized across different farming conditions (Siachos et al., 2024). Biosensors and other monitoring technologies can also support livestock health management (Neethirajan et al., 2017). Such alerts can help farmers investigate potential problems earlier, although they do not replace direct examination or veterinary diagnosis. Earlier detection may allow timely intervention and reduce animal suffering. These technologies can also help breeders collect information on important traits such as health and reproductive performance.

Planning smarter matings—Breeders face a tricky balancing act. They want to improve genetic merit while avoiding excessive inbreeding, which can increase the risk of inherited disorders, reduce fertility and affect performance over generations. Computer-based breeding programmes

can combine genetic merit, relationships among animals and multiple breeding objectives to identify suitable mating pairs. AI may assist with these decisions, but conventional genetic and statistical methods also play an important role. Careful mating plans can help improve a herd while conserving genetic diversity.

Picture a dairy farm where digital monitoring tools are in use. Before sunrise, a phone screen shows the farmer a short list: one cow is eating less than usual, another may be approaching estrous, and a third has been walking slightly unevenly for two days. These changes might have gone unnoticed during routine observation. The farmer still walks through the shed and checks the animals, but now has additional information to help decide where to look first.

What is in it for us?

One of the most important benefits is the potential to accelerate genetic improvement. When breeders can identify genetically superior animals at a younger age, desirable traits may be introduced into a herd more quickly. But speed is not the whole story.

Animal welfare can benefit from better monitoring too. If a sensor warns a farmer about a sick animal before obvious signs appear, treatment can begin sooner. Breeding programmes can also give more weight to health, fertility and longevity, rather than focusing mainly on production.

Better records also mean more informed and consistent breeding decisions. When animals are assessed using reliable measurements, breeders can rely less on memory or appearance alone and make decisions based on a wider range of evidence.

There is an environmental angle as well. Animals that convert feed into milk, eggs or meat more efficiently may require less feed to produce the same amount of output, helping reduce pressure on land and other resources. However, the overall environmental benefit depends on how the animals are raised and how the production system is managed. These technologies may eventually become more accessible to small and medium-sized farms, too, although equipment costs, internet connectivity, technical support and access to reliable data remain important challenges.

Not everything that glitters is gold

As with any new technology, a few cautions are in order. First, AI is only as good as the data it is trained on. If records are patchy, mislabelled or collected from only a few farms, its predictions may be unreliable when applied to other animals or farming systems.

Computer scientists have a blunt phrase for this: garbage in, garbage out.

Second, there is the question of who gets to benefit. Sensors, software and genetic testing cost money, and farmers in resource-limited regions may be left behind unless costs fall and support systems are built. A technology that helps only the largest farms could widen existing inequalities instead of reducing them.

There is also the matter of data ownership. Farm data is valuable, and farmers should have a say in how their data is collected, accessed, shared and used.

Another important concern is the protection of genetic diversity. If breeding decisions rely too heavily on the same criteria or favour a narrow group of animals, genetic diversity could decline. This may leave livestock populations less able to cope with emerging diseases and changing environmental conditions. Local and traditional breeds, often well adapted to their environments, deserve a place in the picture.

Finally, there are ethical questions. Continuous monitoring should support animal welfare, not focus solely on productivity or profit. And a prediction from a computer should never replace a breeder's experience, a veterinarian's judgement or simple compassion.

The road ahead

The story of animal breeding has always been about people using the best tools of their time, from careful observation to statistics to DNA. AI is the next chapter, not a replacement for the earlier ones. Used wisely, it can help us breed animals that are healthier, hardier and more environmentally sustainable.

The goal is not a farm run by machines. It is a farm where people have better information, make better-informed decisions and spend less time guessing.

The barn of the future may hum with sensors and screens, but it will still need someone who knows each animal and cares about its wellbeing. The best breeding decisions are likely to come from a partnership: the farmer's experience and AI's ability to analyse data, working side by side.

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Volume: 06 Issue No: 10

ORGANIC INPUTS: FOR QUALITY AND FRAGRANT JASMINE FLOWERS

Article ID: AG-VO6-I10-40

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Abstracts

Jasmine crop is a main profitable flower crop for its fragrance, attractiveness, commercial essential oil. There flowers are used for religious functions, making garlands, cosmetics and also for perfumes industries for commercial scented products like body spray, soap, shampoos etc. The major setback is quality of jasmine flowers due to excessive application of chemical inputs like fertilizers, insecticides and fungicides to manage the plant growth, pest and diseases, which in turn affects the quality, fragrance and shelf life. There are many study reports for the application of organic inputs have the effects like improving the root and shoot growth, branching and flowering. In addition, enhances the quality of jasmine concrete and further organic inputs improves the soil fertility and tolerated the stress condition. The important organic inputs for nutrient purpose are Farm Yard Manure (FYM), vermicompost, green manure, oil cakes and bio-fetilizers. For pest management organic inputs viz., Neem based products like Neem cake, Neem oil, insect trapes are in practice and border crops for nematode management. The biocontrol agents like Bacillus sp., and *Trichoderma* sp., are used for the management of diseases in the crop. The major advantage for organic jasmine production relays on sustainable quality flower production with more shelf life, which ultimately fetches more price in the market.

Key Words: Jasmine, Organic Inputs, Root and Shoot growth, Fragrance, Income

Introduction

Jasmine belongs to the family Oleaceae and economically important species are *Jasminum grandiflorum* (Royal Jasmine),*Jasminum sambac* (Arabian Jasmine /Mogra)

Jasminum auriculatum (Juhi Jasmine). Among the three types, the Mogra or Sambac type is major type, which is being cultivated in major area by famers for the commercial marketing. Increased flower production, and quality are the main purposes to be numbered in commercial jasmine flower production. Jasmine cultivation is important in Tamil Nadu and other parts of India because of the high demand for fresh flowers and fragrant. Recently, the impact of Organic Fertilizers for crop productivity and tolerance for abiotic stress reported by Liu et *al*., (2024). Excessive use of inorganic fertilizers results less quality flowers and more cost and also adverse effect on soil fertility and pollution to soil health (Bhatia and Gupta, 2007). The quality is being affected by the excessive and continuous application of chemical fertilizers, pesticides, fungicides, herbicides and in turn reduces the soil organic carbon and adversely affects to optimum size, fragrance and shelf life soil biological activity over time. The importance for the application of organic manures like FYM, Vermicompost and bio fertilizers for the crop cultivation of soil nutrients to available form through mineralization process. In the soil, organic inputs or manures and bio fertilizers paves the way for easy uptake of nutrients compared to chemical fertilizers nutrients Bio- fertilizers or microbial inoculants are cost effective source and also reducing the cost of inorganic fertilizer application in addition to increasing the soil quality and soil fertility besides more flower yield.

The nitrogen fixing bacteria, Phosphorus solubilising bacteria are mineralizing or transforming the unavailable nutrients into available forms (Boraste *et al*., 2009). Organic inputs such as farmyard manure (FYM), compost, vermicompost, oil cakes, biofertilizers, liquid organic manures, and beneficial microbial inoculants can improve soil fertility and support sustainable jasmine production. Organic inputs inputs enhances the soil physical, chemical, and biological properties, improve nutrient availability, stimulate root growth, and promote vegetative growth, flowering, flower yield, and quality. Addition of organic manures to the crop cultivation ultimately reduces cost of cultivation through saving the cost of chemical fertilizer purchase and also reduces the soil pollution. (Sharma, 2005). The efficiency of such microbial formulations is higher under chemical free condition (Sateesh and Sivasakthivelan, 2013).

Farmyard manure (FYM), compost, vermicompost, oil cakes, biofertilizers, liquid organic manures, and beneficial microbial inoculants are examples of organic inputs that can enhance soil fertility and promote sustainable jasmine production. Neha Chopde *et al*., (2017) reported that the integrated nutrients management with using organic inputs increased the yield

and quality of Jasmine. These inputs improve the physical, chemical, and biological properties of the soil, increase the availability of nutrients, increases root development, and maximize the vegetative growth, flowering, flower yield, and quality. Many research findings on jasmine stated that the organic manures and bio fertilizers are very effective when used in an integrated nutrient- management method than as single inputs (Kuchanwar, 2001). Organic inputs mainly improve the soil microbial activity and nutrient cycling, whereas the biofertilizers help mobilize nutrients and improve their availability to plants. Studies on jasmine show that organic fertilizers and biofertilizers shown good result when applied in nutrient management approach instead of single application. Organic inputs are very essential and crucial for crop growth and development in Jasmine crop.

MAJOR ORGANIC INPUTS FOR JASMINE CULTIVATION

The major manure are widely used for jasmine crop cultivation are compost, FYM, Oil cakes, biofertlizers are mainly for the uptake of organic carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, and micronutrients to improve vegetative growth parameters like root, shoot and flower induction. Farmyard manure and compost enhances the soil organic carbon and improves the load the soil microorganisms. Vermicompost for improving the beneficial microorganisms, enzymes, and plant growth regulators. Oil cake can be used as nutrient-rich organic amendments. Potassium-solubilising bacteria helps mobilise potassium from soil minerals. The nutrient potassium is important for plant vigour, bud development, flower quality, and stress tolerance. Increasingly used organic manure in jasmine cultivation should be applied through soil drenching or foliar spraying (Table: 1).

Table-1: Major Organic inputs for Jasmine Cultivation

Name of the Organic Manure	**Sources of Nutrients**	**Positive impact on jasmine crop**
Solid Organic Manure		
Farmyard manure (FYM)	Organic carbon (OC), Nitrogen, Phosphorus and Potassium (N, P,K) and Micro nutrients (MN)	Root and Shoot growth and soil fertility
Vermicompost	Macro and Micro nutrients,	Enhanced root growth, more

	Beneficial microorganisms and Plant growth regulators	branching and flowering
Bio Compost	Organic Matter	Soil fertility and nutrients
Neem cake	Nitrogen and active compounds	Nematode control and nitrogen
Groundnut cake	Organic Matter	Plant growth and flowering
Liquid Bio organic manure		
Vermiwash	Liquid nutrients	Plant growth and vigor
Panchagavya	All Nutrients and plant-growth regulators	Crop growth and flowering
Jeevamrutham	Beneficial microbial activity	For soil microflora
Fish Amino Acid	Nutrients	Crop growth and new shoots
Biofertilizers		
Azospirillum	Biological nitrogen fixation	Soil nitrogen
Phosphate-solubilising bacteria	Solubilization of Phosphorus	Root growth and flowering
Potassium-solubilising bacteria	Mobiliser soil potassium	Flower bud and quality
Arbuscular mycorrhizal fungi	Nutrient and Water Uptake	Enhances root growth and stress tolerance
Biopesticides		
Trichoderma sp.	Soil fungi	Root disease management
Bacillus sp.	Soil Bacteria	Plant Disease Management
3 G Solution	Plant Ingredients	Repellent of Pest
5 leaf or 10 leaf solution	Plant active ingredients	Avoidance for pest in crop
Traps (Yellow and Light)	Attractants	To attract pest of crop

Panchagavya is an organic formulation from cow by products like cow dung, cow urine, milk, curd and ghee, which contain macro and micro nutrients, beneficial microorganisms, and plant-growth regulators. Foliar application at seedling and flowering stage influences the leaf development, branching, flower-bud formation, and more number of flowers per plant.

Jeevamirutham is a microbial formulation used for soil biological activity, nutrient cycling and enhances the beneficial soil microorganisms.

Vermiwash is a liquid product obtained from vermicomposting systems. It contains soluble nutrients and microbial metabolites and may be used as a diluted foliar spray or soil application. Plant-based liquid manures agricultural-waste-based liquid manures may provide nutrients and organic compounds. Studies using organic liquid fertilizers indicate their potential to support plant growth and Flowering (Figure: 1)

Figure:1- Jasmine in the flowering stage



IMPORTANCE FOR ORGANIC INPUTS FOR JASMINE CROP

1. Crop growth
2. Flowering
3. Flower quality and Essential oil

EFFECT OF ORGANIC MANURES FOR JASMINE CROP GROWTH

The jasmine crop growth is mainly enhanced through nutrient uptake for increased root development, microbial activity, and soil moisture in the organic inputs applied field.

- Plant growth
- Root length
- Shoot length
- Number of branches and leaves
- Leaf canopy
- Nutrient Uptake

- Plant organic matter

EFFECT OF ORGANIC MANURES FOR JASMINE FLOWERING

Organic manures alone may release nutrients slowly. Therefore, combinations of organic manures with suitable biofertilizers, or integrated use with reduced mineral fertilizers, may provide more consistent yield than the use of a single organic input. Studies on jasmine nutrient management have reported favourable growth, yield, and quality responses from integrated plant nutrition.

- Flowering
- Initiation of flower buds
- More flowers per plant
- Flower weight and big bud
- More yield per plant
- More yield per hectare
- Lengthy flowering period

EFFECT OF ORGANIC MANURES FOR JASMINE FLOWER QUALITY AND ESSENTIAL OIL

The applied organic nutrient management useful for flower quality due to integrated plant nutrient management. Enhancing the quality parameters like bud size, flower weight, freshness, fragrance and colour with shelf life.

INTEGRATED NUTRIENT MANAGEMENT IN JASMINE

Integrated nutrient management consist of organic manures, bio fertilizers, and mineral nutrients. The organic inputs provide immediate nutrients and sustainable nutrient release depends on type of soil organic matter. For example, vermicompost is readily available nutrient and it's Azospirillum for biological nitrogen support, improved phosphorus availability, potassium mobilisation.

ADVANTAGES OF ORGANIC MANURES FOR JASMINE CROP

Organic inputs also support nutrient cycling during the crop period and reduce dependence on highly soluble nutrient sources. The excessive or repeated application without soil testing may cause nutrient accumulation to the soil. Organic inputs offer several benefits:

- ✓ Sustainable flower production
- ✓ Leaf production

- ✓ Root growth
- ✓ Number of flower buds
- ✓ Flower yield
- ✓ Beneficial microbial population
- ✓ Soil microbial activity
- ✓ Nutrient availability
- ✓ Soil aeration
- ✓ Less nutrient losses
- ✓ Maximize root proliferation
- ✓ Better nutrient retention
- ✓ Enhances root development
- ✓ Sustained vegetative growth and flowering
- ✓ Better Growth in plants
- ✓ Primary and secondary stems
- ✓ Production of leaves
- ✓ Development of roots
- ✓ Quantity of flower buds
- ✓ Yield of flowers
- ✓ Population of soil microbes

ADVANTAGES OF ORGANIC MANURES FOR THE SOIL

- ✓ Improved water-holding capacity
- ✓ Microbial activity
- ✓ Improves organic carbon
- ✓ Soil aggregation
- ✓ Bulk density
- ✓ Water-holding capacity
- ✓ Cation-exchange capacity
- ✓ Nutrient availability
- ✓ Soil enzyme activity
- ✓ Beneficial microbial populations
- ✓ Sustains soil fertility

- ✓ Increase microbial activity
- ✓ Nutrient-use efficiency
- ✓ More root growth
- ✓ Enhanced water retention
- ✓ Less usage chemical fertilisers
- ✓ Sustainable flower production

CONSTRAINTS IN ORGANIC INPUTS

- ✓ Variation in organic input Nutrient content
- ✓ Slow Nutrient release
- ✓ More quantities for application
- ✓ Labour intensive
- ✓ Substandard compost contains weed seeds or pathogens
- ✓ Organic Manure performance differs for soil and climate
- ✓ Organic inputs alone not balanced for jasmine crops

Conclusion

Organic inputs are essential for quality and fragrant and sustainable yield in jasmine crop. The organic manures like Farm Yard Manure (FYM), bio- compost, vermicompost, biofertilizers, oil cakes, liquid organic inputs like panchagavya, jeevaamirtham are supporting the plant growth, flowering, flower yield, and quality in addition to root growth, and nutrient-use efficiency. Further, organic inputs improves the soil organic matter, nutrient availability, microbial activity, Based on the study findings, integrated use of organic inputs and bio fertilizer along with soil test based chemical fertilization in jasmine crop contributes good yield with quality. Integrated organic nutrient management also contribute more productive with economically viable and environmentally sustainable jasmine cultivation.

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Volume: 06 Issue No: 10

BEHIND THE FEVER: SPOTTING THE WARNING SIGNS OF SCRUB TYPHUS

Article ID: AG-VO6-I10-41

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Introduction

Scrub typhus, also known as bush typhus, is an acute febrile infectious and one of the important re-emerging, vector-borne zoonotic, potentially life-threatening disease caused by *Orientia tsutsugamushi.* It is an obligate intracellular Gram-negative proteobacterium from the Rickettsiales order. It spreads to people through bites of infected chiggers (larval mites), Leptotrombidium sp. The most common symptoms of scrub typhus include fever, headache, body aches, and rash. Scrub typhus is endemic to the Tsutsugamushi Triangle. Most scrub typhus cases occur in rural areas of Southeast Asia, Indonesia, China, Japan, the Indian subcontinent, and northern Australia. Anyone living in or travelling to areas where scrub typhus is found could get infected. In Tamil Nadu, hospital-based studies have reported seroprevalence rates ranging from 10 % to 30 %, highlighting the endemicity of the disease in this region.

Transmission/Reservoir:

Humans acquire the disease from the bite of an infected trombiculid mite (chigger) which act as both the vector and reservoir for the disease and is very small (0.2 – 0.4mm) which can only be seen through a microscope or magnifying glass. The larva is the only stage that can transmit the disease to humans and other vertebrates. Human-to-human transmission is rare.

Incubation period and Risk groups:

The incubation period for the scrub typhus infection is about 5 to 20 days (mean, 10-12 days) after the initial bite. Rural populations are at higher risk of scrub typhus due to the presence of chiggers in natural habitats like vegetation and fields, and frequent outdoor activities such as farming and animal husbandry. Agricultural workers, people living in houses with

shrubs/ bush nearby and travellers in areas with potential exposure to mice and mites, e.g. camping, rafting, or trekking.

Signs and symptoms

Symptoms of scrub typhus usually begin within 10 days after infection, which include:

- A high fever, Chills, Headache, muscle and body aches, physical weakness, fatigue and joint pain are the critical symptoms of Scrub Typhus.A dark, scab-like region at the site of the chigger bites (also known as **an eschar)** may also be noted. Recently, WHO identified encephalitis. Mental changes, ranging from confusion to coma, are seen in affected individuals. Lymph nodes are enlarged, and respiratory Symptoms like cough and difficulty breathing are common. Persons will also experience gastrointestinal issues like nausea, abdominal pain, and diarrhoea. Finally, Scrub Typhus often impacts various body organs and causes severe complications such as liver and kidney dysfunction, resulting in Multi-Organ Failure(CDC, 2024).

The most common signs are similar to a variety of other infectious diseases (Typhoid fever, Malaria, Murine typhus, Leptospirosis, Dengue fever, Meningococcal infection, etc.) which should be taken into consideration. If not treated appropriately; scrub typhus can be fatal and may lead to organ damage and severe bleeding.

Eschar at the site of a chigger bite



Diagnosis

Serologic assays include ELISA and indirect immunoperoxidase (IIP) assays are the most frequently used methods for confirming cases of scrub typhus. The disease is typically confirmed by documenting a four-fold rise in antibody titer between acute and convalescent samples. Because antibody titers may persist in some individuals for years after the original exposure, only demonstration of recent changes in titers between paired specimens can be considered

reliable confirmation of an acute scrub typhus infection. The most rapid and specific diagnostic assays for scrub typhus rely on molecular methods like polymerase chain reaction (PCR), which can detect DNA in a whole blood, eschar scab, or tissue sample.

Early Treatment & Disease Management

The treatment for suspected or confirmed cases includes **doxycycline** (first-line choice for adults and children).Use **azithromycin** or rifampicin for pregnant patients, young children where preferred, or individuals with severe tetracycline allergies. Suspected cases should bereported quickly to local public health authorities to track outbreaks and lower complication risks.

Prevention and Control

The preventive measures for scrub typhus include personal protection against chigger mite bites, environmental management, and early medical treatment. There is currently no licensed human vaccine available. People should wear long-sleeved shirts, long trousers tucked into socks, and closed-toe boots when walking through brush, tall grass, or rural areas. Apply EPA-registered insect repellents containing DEET to exposed skin. Avoid sitting or lying directly on bare ground, grass, or scrub; use a mat, blanket, or ground sheet.Clear dense vegetation, tall grass, and scrub around homes, farmyards, and walkways to eliminate chigger habitats.Apply insecticides or acaricides to infested soil and brush areas to break the mite transmission cycle.Manage small mammal and rodent populations that harbour the vector mites.

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Volume: 06 Issue No: 10

WASTE TO WEALTH METHOD: AN ENVIRONMENTALLY FRIENDLY APPROACH FOR POULTRY PRODUCTION

Article ID: AG-VO6-I10-42

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Abstract

Rising feed prices and growing quantities of agricultural and food-processing by-products create both a challenge and an opportunity for poultry production. Waste-to-wealth strategies aim to recover nutrients from suitable, traceable by-products through sorting, stabilization, enzymatic processing, microbial fermentation and balanced feed formulation. Rice bran, wheat bran, broken rice, oilseed meals and selected fruit or vegetable residues may supply energy, protein, fibre, minerals and functional compounds, but their use is constrained by compositional variability, antinutritional factors, spoilage and contamination. Controlled fermentation can modify substrate characteristics and produce organic acids; however, benefits depend on the microorganism, substrate, processing conditions and dietary inclusion level. This article reviews promising feed resources, practical processing methods, potential effects on nutrient availability and intestinal health, environmental and economic considerations, and essential feed-safety safeguards. A rice-bran-focused value chain is proposed for local enterprises and future research. The approach can contribute to circular agriculture when quality, efficacy and full processing costs are demonstrated.

Keywords: agricultural by-products; circular bioeconomy; fermented rice bran; feed safety; gut health; poultry nutrition; waste valorization

Introduction

Feed represents a major share of the operating cost of poultry production, making efficient use of safe, affordable ingredients central to profitability. Conventional diets depend on cereal grains, oilseed meals and imported or regionally scarce inputs. Simultaneously, rice mills,

flour mills, oil extraction units, fruit processors and vegetable markets generate nutrient-containing residues. Many are already commercial feed materials rather than literal wastes; the opportunity is to recover additional value from low-grade or underused streams without diverting unsafe materials into the feed chain (Sugiharto, 2022; Manlapig and Matsui, 2025).

Waste-to-wealth in animal nutrition should therefore mean evidence-based upgrading rather than simply mixing discarded materials into feed. The desired product must be nutritionally characterized, safe, stable, traceable and economically competitive. Poultry have relatively limited ability to utilize high-fibre ingredients, so formulation must account for digestible amino acids, available phosphorus, energy density and physical quality (Sugiharto and Nuengjamnong, 2025).

Candidate agricultural by-products

Resource	Potential feed contribution	Key caution
Rice bran	Oil, protein, phosphorus and bioactives	Lipase-related rancidity; phytate; fibre
Wheat bran	Protein, minerals and fibre	Non-starch polysaccharides; variable energy
Broken rice	Starch and metabolizable energy	Low protein; nutrient balancing needed
Mustard/rapeseed meal	Protein	Glucosinolates; fibre; processing history
Groundnut cake	Protein and oil	Aflatoxin risk; batch testing
Fruit and vegetable residues	Selected micronutrients and bioactives	Moisture, pesticides, spoilage and variability
Brewer's spent grain	Protein and fibre	High moisture and fibre; drying cost

Selection should begin with a local inventory of volume, seasonality, competing uses, transport distance, contamination risk and price. Material unsuitable for animal consumption must be excluded even when it appears inexpensive (FAO and IFIF, 2020).

TECHNOLOGIES THAT CONVERT RESIDUES INTO FEED

Physical processing and stabilization

Sorting, sieving, grinding, heat stabilization, extrusion and drying can improve handling, reduce spoilage and control selected hazards. In full-fat rice bran, rapid post-milling lipase activity increases free fatty acids and accelerates rancidity; prompt stabilization is therefore critical. Excessive heating, however, can reduce nutritional quality and raise energy costs (Manlapig and Matsui, 2025).

Enzymatic processing

Phytase can improve access to phytate-bound phosphorus, while xylanase, beta-glucanase, cellulase and protease may alter non-starch polysaccharides or protein fractions. Enzyme efficacy depends on ingredient composition, dosage, pH, temperature and the whole diet. Enzymes are not substitutes for contaminant control.

Microbial fermentation

Controlled solid-state or submerged fermentation uses characterized microorganisms to transform components of the substrate. Selected lactic acid bacteria may generate organic acids and alter phytate availability; Bacillus and suitable fungal strains may produce hydrolytic enzymes. Neither increased crude protein percentage nor lower pH alone establishes higher usable nutrient yield or feed safety. Dry-matter recovery, absolute nutrient mass and contamination must be measured (Manlapig and Matsui, 2025; Qui and Linh, 2025).

RICE BRAN AS A PRACTICAL MODEL FOR CIRCULAR POULTRY NUTRITION

Rice bran is particularly relevant in rice-producing regions such as West Bengal. Its value arises from residual oil, protein, phosphorus and phenolic constituents. Constraints include fibre, phytate, variable composition and rapid deterioration of unstabilized bran. Fermentation is promising, but the most appropriate organism, duration and final dietary inclusion must be established experimentally (Manlapig and Matsui, 2025; Qui and Linh, 2025).

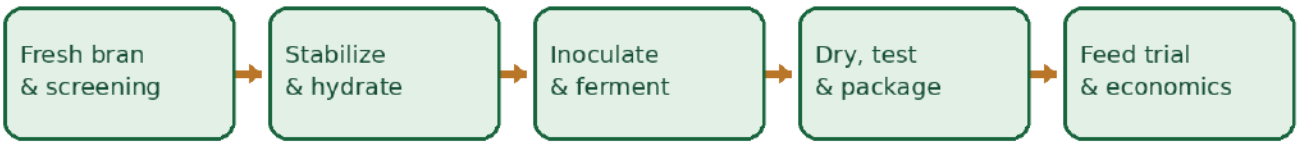


Figure 1. Schematic of rice-bran conversion into a tested poultry feed ingredient.

HOW RICE BRAN CAN BE CONVERTED INTO A FEED INGREDIENT

- ✓ Fresh rice bran should be sourced from traceable rice mills and inspected for moisture, nutrient composition, mould growth and contaminants. Spoiled or suspect material must be rejected rather than diverted into animal feed.
- ✓ When necessary, controlled heat stabilization helps limit lipase activity and rancidity. Cleaning and particle-size adjustment improve handling and uniform processing.
- ✓ For biological upgrading, moisture-adjusted rice bran can be fermented with a characterized, feed-suitable starter culture, such as an appropriately evaluated lactic acid bacterium or Bacillus strain. Culture selection should depend on safety, substrate compatibility and reproducible processing performance.
- ✓ During controlled fermentation, temperature, pH, moisture and microbiological quality require monitoring. The optimal process differs among strains and substrates; there is no universally applicable incubation time.
- ✓ The processed ingredient is subsequently dried and packaged to limit moisture uptake and deterioration. Its moisture, water activity, lipid oxidation, microbial safety and nutritional composition must be checked.
- ✓ Only quality-tested material should enter nutritionally balanced poultry diets. Its value is best judged by comparing it with an equivalent amount of unfermented rice bran and by measuring feed efficiency and economic returns.
- ✓ Fermentation is a promising processing method, but neither acidification nor drying reliably eliminates pre-existing mycotoxins. Safe sourcing and independent quality testing remain indispensable.

NUTRITIONAL AND INTESTINAL-HEALTH IMPLICATIONS

Processing may modify fibre fractions, lower phytate and improve availability of selected nutrients, although outcomes vary widely. Apparent increases in crude protein concentration can arise from loss of carbohydrate dry matter; absolute protein recovery and digestible amino acid supply provide a more useful assessment. The inclusion of fermented ingredients may alter gut microbial communities, short-chain organic acid exposure and intestinal morphology, but a particular strain–substrate combination cannot be assumed to improve growth or immunity (Manlapig and Matsui, 2025; Qui and Linh, 2025).

Published poultry feeding studies have assessed body weight, feed intake, feed conversion ratio, digestibility, intestinal microbiota and gut morphology. These outcomes should be interpreted in relation to feed composition, processing method, dietary inclusion level and husbandry conditions rather than assumed to improve in every case.

ENVIRONMENTAL BENEFITS: OPPORTUNITIES AND TRADE-OFFS

Using safe by-products may reduce disposal burdens and partially replace primary crops in feed. Local processing could shorten some supply chains and create new outlets for rice-milling residues. However, fermentation requires water, electricity, drying fuel, packaging and transport; these inputs can offset environmental gains. Claims of reduced greenhouse gas emissions or carbon footprint should be supported by a defined life-cycle assessment that compares the upgraded ingredient with a realistic baseline (Sugiharto, 2022).

ECONOMICS AND FARMER-LEVEL OPPORTUNITIES

The lowest raw-material purchase price does not necessarily produce the lowest feed cost. A realistic costing model includes collection, sorting, stabilization, starter preparation, fermentation, drying, quality testing, storage losses, packaging and transport. Farmers and feed mills should compare nutrient-adjusted formulation cost and feed cost per kilogram of body-weight gain rather than the price per kilogram of ingredient alone. A pilot cooperative involving a rice mill, a small processing unit and nearby poultry producers could test a traceable, local circular supply chain.

SAFETY, QUALITY CONTROL AND LIMITATIONS

Priority hazards include mycotoxins, pesticide residues, pathogenic organisms, heavy metals where relevant, physical contaminants and oxidative rancidity. Every batch requires suitable acceptance criteria and documented sampling. A safe starter culture does not make contaminated substrate safe; product acidification does not prove absence of pathogens; and drying does not reliably destroy toxins. Standard operating procedures, hygiene, traceability and applicable feed regulations are essential (FAO and IFIF, 2020).

Further advances will depend on comparing suitable microbial cultures, measuring nutrient changes on a dry-matter basis, establishing storage stability, and testing practical feeding responses. Independent cost accounting and environmental life-cycle assessment can help determine whether a particular processing method is genuinely preferable to direct use of an existing safe feed by-product.

Research should compare indigenous and reference fermentation cultures; quantify phytate, fibre and organic acid changes; report dry-matter mass balance; establish storage stability; and test several inclusion levels in nutrient-balanced broiler diets. Larger-scale validation should address batch-to-batch consistency, energy consumption, life-cycle impacts and market acceptance. Where a novel product is claimed, strain-specific and process-specific evidence should underpin patentability and commercialization decisions.

Conclusion

Waste-to-wealth approaches can make poultry feeding more resource-efficient by converting selected agricultural and agro-industrial by-products into safe, characterized ingredients. Rice bran provides a practical example of how stabilization, microbial fermentation and quality-controlled formulation might add value to a familiar milling by-product. The potential gains in nutrient accessibility, gut health and farmer income are promising but must be confirmed with properly controlled feeding trials, feed-safety testing and realistic cost accounting. Successful adoption depends on integrating biotechnology with practical feed formulation, local enterprise development and measurable environmental performance.

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Volume: 06 Issue No: 10

OCEAN HEALTH AND SUSTAINABLE FISHERIES: AN INDIAN PERSPECTIVE

Article ID: AG-VO6-I10-43

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Introduction

Oceans play a vital role in maintaining ecological balance, regulating climate, supporting biodiversity, and providing food and livelihoods to millions of people. India, with a coastline of approximately 11,000 km and rich marine resources, depends heavily on healthy oceans for fisheries, coastal employment, and economic development. However, marine pollution, overfishing, climate change, and habitat destruction are increasingly threatening ocean health. Sustainable fisheries management and marine ecosystem conservation are therefore essential to ensure long-term ecological and economic security.

Understanding Ocean Health

Ocean health refers to the ability of marine ecosystems to maintain biodiversity, ecological functions, and resilience while supporting human well-being. Healthy oceans provide essential services, including carbon storage, nutrient cycling, coastal protection, and food production. Coral reefs, mangroves, seagrass beds, and estuaries serve as important habitats and breeding grounds for numerous marine organisms. Maintaining these ecosystems is crucial for sustaining fish populations, protecting coastal communities, and ensuring the continued availability of marine resources.

Major Threats to Ocean Health in India

Marine pollution: Untreated sewage, industrial effluents, agricultural runoff, plastics, and discarded fishing gear contribute to marine pollution. Microplastics and chemical

contaminants can affect marine organisms, enter food webs, and potentially threaten human health.

Overfishing and destructive fishing practices: Excessive fishing pressure, juvenile fish capture, and unsustainable fishing methods can reduce fish stocks and disturb marine food webs. These practices threaten biodiversity and the livelihoods of fishing communities.

Climate change: Rising sea temperatures, ocean acidification, and changes in ocean circulation affect fish distribution, coral reefs, and marine productivity. Coastal communities are also increasingly vulnerable to sea-level rise, erosion, and extreme weather events.

Habitat degradation: Coastal development, dredging, and the destruction of mangroves, coral reefs, and seagrass beds reduce essential habitats for marine organisms. Protecting these ecosystems is necessary for maintaining biodiversity and supporting fisheries.



Figure 1: Ocean health and sustainable fisheries for a resilient marine ecosystem in India

Sustainable Fisheries Management

Sustainable fisheries management aims to harvest fish responsibly while maintaining healthy fish populations and marine ecosystems. Effective management measures include regulating fishing effort, enforcing seasonal fishing bans, protecting juvenile fish, and controlling destructive fishing practices.

In India, the implementation of the National Policy on Marine Fisheries, 2017, provides a framework for responsible fisheries development and resource conservation. Science-based stock assessments, improved catch monitoring, and ecosystem-based management can strengthen fisheries governance. Promoting responsible fishing practices, reducing bycatch, and

encouraging the use of selective fishing gear can minimise ecological impacts. Sustainable aquaculture and alternative livelihood opportunities can also help reduce pressure on wild fish stocks.

Marine Ecosystem Restoration

Restoring degraded coastal ecosystems is an important strategy for improving ocean health. Mangroves protect coastlines from erosion, provide nursery habitats for fish and crustaceans, and store significant amounts of carbon. Coral reefs and seagrass beds support biodiversity, fisheries, and coastal protection. In India, mangrove restoration, coral reef conservation, and seagrass protection can contribute to marine biodiversity conservation and climate resilience. Restoration initiatives should be based on scientific assessments, use suitable native species, and involve local communities to ensure long-term success.

Technology for Ocean Monitoring

Modern technologies can improve marine resource assessment and environmental monitoring. Satellite remote sensing, geographic information systems (GIS), drones, and geographic positioning systems (GPS) help monitor coastal changes, fishing activities, habitat degradation, and pollution. Digital catch reporting, vessel tracking, and fisheries data analysis can support evidence-based management. Integrating these technologies with field surveys and community observations can improve decision-making and strengthen conservation efforts.

Government Initiatives and Community Participation

India has introduced various programmes and policies to support marine conservation, fisheries development, and coastal ecosystem protection. The Pradhan Mantri Matsya Sampada Yojana (PMMSY) promotes sustainable fisheries development, infrastructure improvement, and fisheries management. Marine protected areas and coastal habitat restoration initiatives also contribute to biodiversity conservation.

However, government action alone cannot ensure sustainable ocean management. Fishers, researchers, government agencies, industries, and coastal communities must work together. Community-based monitoring, responsible waste disposal, reduced plastic use, and awareness programmes can support conservation efforts.

Future Prospects

The future of India's marine resources depends on balancing fisheries development with environmental protection. Priorities should include strengthening fisheries regulations,

improving pollution control, restoring coastal habitats, and expanding scientific monitoring. Climate-resilient fisheries management and greater participation of fishing communities are also essential.

Investment in research, technology, and environmental education can help develop practical solutions to emerging marine challenges. Collaboration among government institutions, universities, research organisations, and fishing communities will be critical to achieving long-term sustainability.

Conclusion

Ocean health and sustainable fisheries are closely interconnected. Pollution, overfishing, climate change, and habitat degradation threaten marine biodiversity and the livelihoods of coastal communities. Strengthening fisheries management, restoring coastal ecosystems, adopting modern monitoring technologies, and encouraging community participation can help address these challenges. Protecting India's marine environment is not only an ecological responsibility but also an investment in food security, economic development, and the well-being of future generations.

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Volume: 06 Issue No: 10

FOREST FIRE-INDUCED DEGRADATION OF MEDICINAL AND AROMATIC PLANT DIVERSITY IN THE WESTERN HIMALAYA: ECOLOGICAL IMPACTS, REGENERATION AND CONSERVATION STRATEGIES

Article ID: AG-VO6-I10-44

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Abstract

Medicinal and aromatic plants (MAPs) are important components of Himalayan biodiversity, supporting traditional healthcare, local livelihoods and herbal industries. However, recurrent forest fires, particularly in the Western Himalaya, may alter their diversity, population structure, regeneration and habitat quality. Fire effects depend on severity, frequency, season, vegetation type and species-specific adaptations. Potential consequences include plant mortality, changes in soil properties and seed banks, altered competition, reduced recruitment and shifts in community composition. Fire may also influence secondary metabolites and essential-oil composition, although direct evidence of its effects on medicinal quality in Himalayan MAPs remains limited. This review synthesizes the ecological mechanisms of fire-induced degradation, its implications for MAP diversity and regeneration, interactions with climate change and human pressures, and approaches to conservation and restoration. Regional studies from Uttarakhand demonstrate that fire frequency is associated with differences in vegetation diversity and regeneration, although responses vary among forest types. The review proposes an integrated framework combining fire-risk mapping, species-level monitoring, assisted natural regeneration, sustainable harvesting and community participation.

Keywords: Western Himalaya, forest fire, medicinal and aromatic plants, biodiversity, conservation.

1. Introduction

The Indian Himalayan Region (IHR) is characterized by substantial floristic diversity, pronounced altitudinal gradients and a wide range of forest ecosystems. Variations in climate, topography, soil and moisture support numerous medicinal and aromatic plants (MAPs), which contribute to ecological processes, traditional healthcare and regional economies. Himalayan aromatic plants are particularly important for their essential oils, traditional uses and bioactive compounds (Joshi *et al*., 2016).

Despite their ecological and socioeconomic importance, MAPs face increasing pressure from habitat fragmentation, grazing, destructive harvesting, land-use change and forest fires. Fire is a major vegetation disturbance in parts of the Western Himalaya, where seasonal drying and combustible litter can facilitate the spread of surface fires (Bond and Keeley, 2005). Its effects depend on fire frequency, intensity, severity, timing and the characteristics of the affected ecosystem (Keeley, 2009).

Fire-induced degradation may extend beyond immediate plant mortality to include changes in soil conditions, seed-bank viability, regeneration, competition and community composition. These changes can affect medicinal-resource availability even when general vegetation cover recovers. However, fire responses differ among species: some plants may resprout or establish in disturbed microsites, whereas others may experience recruitment failure.

This review examines forest-fire regimes, ecological degradation mechanisms, impacts on MAP diversity and regeneration, possible phytochemical responses, and conservation strategies, with particular relevance to Uttarakhand and Himachal Pradesh.

2. Forest Fire Regimes in the Indian Himalayan Region

Forest-fire regimes are characterized by frequency, intensity, severity, seasonality, extent and spatial distribution. These factors determine the type and magnitude of ecological damage. Fire frequency describes how often an area burns, whereas fire severity refers to the ecological effects of burning.

In the Western Himalaya, dry-season conditions, accumulated litter, topography and vegetation structure influence fire susceptibility. Chir-pine forests dominated by Pinus roxburghii are important in regional fire management because dry pine needles can contribute to surface fuels. Human activities, including deliberate burning, agricultural practices and unattended ignition sources, may further increase fire occurrence.





The Forest Survey of India's India State of Forest Report 2023 provides national forest and fire-monitoring information useful for identifying vulnerable landscapes, although its broad-scale information cannot directly establish damage to individual MAP populations.

Regional evidence highlights the ecological importance of fire frequency. Bargali et al. (2023) examined sal, chir-pine and mixed forests in Uttarakhand using satellite-derived fire-frequency classes and field vegetation surveys. Their findings showed differences in tree diversity and regeneration among fire-frequency classes and forest types.

3. Diversity and Ecological Importance of Himalayan MAPs

The Indian Himalaya supports MAPs ranging from annual herbs and perennial rhizomatous plants to shrubs and trees. Their distribution depends on elevation, temperature, moisture, soil conditions, competition and habitat history. Representative taxa of conservation interest include *Aconitum heterophyllum*, *Picrorhiza kurroa*, *Nardostachys jatamansi*, *Valeriana jatamansi*, *Angelica glauca*, *Berberis* species and *Artemisia* species. These taxa occupy different habitats and should not be assumed to have identical fire responses.

Ecologically, MAPs contribute to nutrient cycling, pollination, food webs and habitat structure. Their flowers and fruits provide resources for other organisms, while ground-layer vegetation can influence soil-surface protection and microsite conditions. The loss of a locally restricted medicinal species may therefore affect both biodiversity and ecosystem functioning.

4. Mechanisms of Fire-Induced Vegetation Degradation

- **Direct thermal injury**

Fire can damage leaves, stems, buds, bark, roots and underground storage organs. Seedlings and small herbs may be particularly exposed to heat near the soil surface. Survival depends on plant size, tissue moisture, bark characteristics and the position of regenerative buds.

- **Soil properties and nutrient cycling**

Fire can alter soil organic matter, pH, nutrient availability, microbial communities and water

infiltration. These effects depend on fire severity, vegetation, soil characteristics and post-fire rainfall (Certini, 2005). Some low-severity fires may temporarily increase nutrient availability, while severe or recurrent burning can reduce organic matter, expose soil and increase erosion risk.

- **Seed banks and regeneration**

Fire may destroy seeds, modify dormancy conditions or create open microsites suitable for germination. The outcome depends on seed thermal tolerance, burial depth, dormancy and the timing of seed production.

- **Competition and vegetation succession**

Burning can open the canopy, increase light availability and change competition for water and nutrients. Some fire-tolerant or disturbance-adapted species may increase, while sensitive species decline. Regional evidence from Uttarakhand indicates that frequent fires can be associated with shifts in vegetation diversity and regeneration (Bargali *et al*., 2023).

5. Effects on MAP Diversity, Population Structure and Regeneration

A study of floristic diversity in Uttarakhand reported declining herb richness across increasing fire-frequency classes, with 37 herb species recorded in the no-fire class and 12 in the high-fire-frequency class in the studied forests (Bargali *et al*., 2022).

These findings are relevant to medicinal herbs but do not establish that all MAP species respond similarly.

Population structure is equally important. A population dominated by mature plants may appear stable while recruitment is insufficient to replace future mortality. For trees and shrubs, height and diameter classes can reveal regeneration patterns; for herbs and rhizomatous species, shoot density, clump size and survival of underground organs may be more informative.

Monitoring should therefore include species richness, abundance, seedling and juvenile density, survival, resprouting, flowering and fruiting. Comparisons between burned and unburned plots should account for elevation, forest type, slope, aspect, grazing and harvesting pressure. Long-term monitoring is preferable because single-season surveys cannot reliably establish population persistence.

6. Fire Effects on Medicinal and Aromatic Quality

Medicinal and aromatic plants produce secondary metabolites, including terpenoids, phenolics and other bioactive compounds. Their composition varies with genotype, plant age,

season, elevation, water availability and other environmental conditions. Himalayan aromatic plants have been documented for their essential-oil composition and reported biological activities (Joshi *et al*., 2016).

Medicinal quality cannot be evaluated solely through the concentration of one compound. Research should measure essential-oil yield, chemical composition, relevant marker compounds and, where appropriate, biological activity. Gas chromatography–mass spectrometry (GC–MS) can help characterize volatile constituents.

7. Conservation, Restoration and Sustainable Management

Effective MAP conservation requires integration of fire prevention, ecological restoration and sustainable resource use.

- **Fire prevention and community participation**: Local fire-warning systems, awareness programmes, preparedness and appropriate fuel management can reduce preventable damage. Management measures should reflect the ecology of each forest type rather than assuming that complete fire exclusion is suitable everywhere.
- **Assisted natural regeneration:** Where surviving plants and natural recruitment are adequate, protection from repeated burning, grazing and harvesting may be sufficient. Where regeneration is poor, locally appropriate propagation, enrichment planting and erosion control may be necessary.
- **In situ and ex situ conservation:** Protecting populations within their natural habitats maintains ecological interactions and local genetic diversity. Seed banks, nurseries, botanical gardens and propagation programs can complement in situ conservation, especially for vulnerable species.
- **Sustainable harvesting:** Collection guidelines should consider the plant part harvested, harvesting season, intensity and recovery period. Cultivation of suitable medicinal species can reduce pressure on wild populations, but should complement rather than replace natural-habitat conservation.

9. Research Gaps and Future Directions

Several gaps limit the development of effective MAP-specific fire-management strategies.

First, species-level evidence remains insufficient. More studies are needed to identify which Himalayan MAPs are fire-sensitive, fire-resilient or dependent on particular post-fire conditions.

Second, short-term vegetation surveys cannot establish long-term population viability; permanent plots should monitor survival, recruitment and reproductive maturity.

Future research should prioritize:

- Long-term demographic studies of threatened and economically important MAPs.
- Comparisons of fire responses among herbs, shrubs, trees and rhizomatous plants.
- Standardized investigations of phytochemical responses to fire.
- Assessment of compound disturbances and harvesting interactions.
- Evaluation of natural regeneration, assisted restoration and community-based management.

Conclusion

Forest fires can alter medicinal and aromatic plant diversity, population structure and regeneration across the Indian Himalaya. Regional studies from Uttarakhand demonstrate associations between fire frequency, floristic diversity and woody-plant regeneration, although responses differ among forest types and species (Bargali *et al*., 2023). These findings support the need for MAP-focused investigations rather than assuming that all medicinal plants respond uniformly to burning. The principal conservation challenge is to maintain viable populations, not merely restore vegetation cover. Fire-related mortality, recruitment failure and altered species composition may reduce medicinal-resource availability, particularly where grazing, destructive harvesting and habitat fragmentation occur simultaneously. Meanwhile, the effects of fire on medicinal efficacy and essential-oil composition remain insufficiently established and require targeted phytochemical research.

An effective conservation framework should combine fire-risk mapping, long-term population monitoring, protection of natural regeneration, species-specific restoration and sustainable harvesting with local community participation. Priority should be given to vulnerable MAP populations in repeatedly burned landscapes. By integrating ecological, demographic and phytochemical evidence, conservation programmes can better protect Himalayan plant diversity while supporting the sustainable use of medicinal resources.

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Volume: 06 Issue No: 10

ALTERNATIVE FEED INGREDIENTS FOR FISH FEED

Article ID: AG-VO6-I10-45

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Abstract

Fish farming is growing fast to feed more people, but the traditional food for farmed fish – fishmeal made from wild fish – is becoming scarce and expensive. This puts pressure on ocean life and raises costs. Scientists and farmers are looking at better options. Plants, insects, leftover animal parts, tiny microbes, and even specially changed crops can all help replace fishmeal. Insects such as black soldier flies, mealworms, and houseflies look especially promising because they are rich in protein and can be grown on waste. Plant ingredients are cheap and plentiful but need careful processing. These new feeds can keep fish healthy, support the environment, and make fish farming more sustainable for the future.

Keywords: Fishmeal, Plant – based ingredients, Insect meal, Feed ingredients

Introduction

The world's population keeps growing, and so does the need for healthy protein foods like fish. Wild fish catches are no longer enough. That is why aquaculture in ponds, cages, or tanks has become so important. Today, nearly half of all the fish we eat comes from farms.

But there is a big problem. Most farmed fish, especially meat-eating species like salmon, trout, and seabass, are fed with fishmeal and fish oil. These are made by grinding up wild fish that are not usually eaten by people. Using so many wild fish for feed puts heavy pressure on ocean stocks. Prices keep rising, and the supply is not reliable. Experts say we need new ingredients that are kinder to the planet, cheaper, and still good for the fish.

Why Traditional Fish Feeds Face Problems

Fishmeal is popular because it has the perfect mix of amino acids (the building blocks of protein) that fish need, and it is easy to digest. However, catching millions of tons of wild fish every year just to make feed is not sustainable. Ocean stocks of small fish used for meal are declining. At the same time, the same fishmeal is also used for chickens, pigs, and pets, so competition is strong.

When farmers try to use more plant meals instead, new problems appear. Many plant ingredients contain natural chemicals called anti-nutritional factors. These can upset the fish's stomach, reduce growth, or even cause inflammation in the gut. Plant proteins also often lack some key amino acids and the special omega-3 fats that fish (and people who eat them) need. That is why researchers are searching for better balances.

Plant-Based Ingredients

Plants are the most common alternative used today. Soybean meal, corn gluten, wheat gluten, canola, sunflower, lupins, and peas all supply protein. They are usually cheaper and more available than fishmeal.

Challenges with plants

The biggest issues are anti-nutritional factors such as trypsin inhibitors, lectins, saponins, phytates, and tannins. These compounds can block digestion, reduce mineral absorption, or damage the intestine. Soybean meal, for example, can cause a condition called "soybean enteritis" in salmon. Many plants are also low in the amino acids lysine or methionine, so feed makers often mix several plant sources or add synthetic amino acids.

Plant oils lack the long-chain omega-3 fats (EPA and DHA) that are important for fish health and for the nutritional value of the final fillet that people eat. Some plant oils also contain too many saturated fats that are harder for cold-water fish to digest.

Opportunities with plants

Processing helps a lot. Heat treatment, extrusion, enzyme addition (such as phytase), and making protein concentrates can remove many harmful compounds and raise the protein level. Soy protein concentrate, for instance, has fewer anti-nutrients and higher protein than regular soybean meal. Plant ingredients also leave a smaller environmental footprint in some ways and can be grown in many countries.

Insect-Based Ingredients – A Rising Star

Insects are one of the most exciting new options. They are rich in protein (often 40–60 % or more), contain useful fats, vitamins, and minerals, and can be raised on organic waste, turning leftovers into valuable feed. This fits the idea of a circular economy, nothing is wasted.

In Europe, several insect species are already allowed in fish feeds: black soldier fly (*Hermetia illucens*), yellow mealworm (*Tenebrio molitor*), housefly (*Musca domestica*), and a few others including silkworm and some crickets. Research shows that these insects can replace a good part of the fishmeal without harming growth in many species.

Black soldier fly larvae

Black soldier fly larvae grow quickly on many kinds of organic waste and are easy to harvest. Trials with rainbow trout, Atlantic salmon, European seabass, and yellow catfish show that replacing 20–50 % (sometimes even more) of fishmeal with black soldier fly meal keeps growth and health good. In some cases, the fish fillets even keep or improve their quality. The larvae can also help recycle aquaculture sludge, closing the nutrient loop.

Yellow mealworms

Mealworms are another strong candidate. Studies on African catfish, rainbow trout, yellow catfish, and European seabass show that mealworm meal can replace 40–80 % of fishmeal in many diets with no big drop in growth. Some trials even report better protein use and stronger immune responses. Defatted mealworm meal works especially well because excess fat is removed.

Housefly maggots

Housefly maggot meal has been tested mainly in tilapia and catfish. Results are positive: growth improves and feed costs can fall, which is important for farmers in developing countries. Inclusion levels of 30–70 % replacement have worked well in several trials.

The chitin question

Insects have an outer shell made of chitin, a tough fibre. Some people worried that chitin would lower digestibility. Newer research shows a more balanced picture. Moderate amounts of chitin can act as a prebiotic, helping good gut bacteria, supporting the immune system, and even improving disease resistance. The effect depends on the fish species and the amount used. Overall, chitin is no longer seen only as a problem; it can bring extra benefits.

Other Alternative Ingredients

Animal by-products

Blood meal, feather meal, and poultry by-product meal are leftovers from meat processing. They are free of the anti-nutrients found in plants and can supply high-quality protein. Blood meal is rich in lysine and histidine. Feather meal needs extra amino acids added, but it is cheap. Careful processing is needed to keep digestibility high and avoid any safety concerns.

Microbial ingredients

Bacteria, yeasts, and microalgae can be grown on waste gases or by-products from other industries. Bacterial meals grown on methane have shown good results in salmon and trout, improving gut health and helping recover from plant-related gut problems. Yeasts act as probiotics and immune boosters. Microalgae can supply protein and the valuable omega-3 fats that plants lack. The main hurdles are still production cost and breaking open the tough cell walls so fish can digest the nutrients.

Genetically improved crops

Scientists have created crops with higher levels of missing amino acids or lower levels of anti-nutrients. These “genetically modified” or gene-edited plants can make plant-based feeds more complete. Safety studies so far show that the modified DNA does not transfer into the fish in any meaningful way. Public acceptance and clear labelling rules remain important points for the future.

Benefits for Fish Health, Quality, and the Planet

When used at the right levels, many alternative ingredients support good growth, healthy organs, and strong immune systems. Some insect meals even help prevent the gut inflammation caused by high levels of soybean meal. Fillet quality, taste, texture, and fat composition can stay the same or even improve. From an environmental view, using insects grown on waste, plant co-products, or microbes reduces the need to catch wild fish and can lower the overall footprint of aquaculture.

Challenges and Next Steps

Several challenges still need attention. Insect production must scale up so prices become competitive. Rules about what insects can eat (substrates) and which species are allowed differ between countries and should become clearer and more consistent. Long-term studies on

different fish species are needed to find the best inclusion levels. Safety checks for contaminants, allergens, and heavy metals must continue. Finally, consumers need clear information so they feel confident about the fish they buy.

The future looks promising. A mix of ingredients some plant, some insect, some microbial will probably give the best results. Research is already testing combinations, such as mixing black soldier fly and mealworm proteins. With continued science, smarter regulations, and investment in large-scale production, alternative feeds can help aquaculture grow sustainably while protecting wild fish stocks and the oceans.

Conclusion

Fishmeal has served aquaculture well for decades, but it cannot keep pace with rising demand without harming the oceans. Plant proteins, insect meals, animal by-products, microbes, and improved crops all offer workable alternatives. Insects stand out because of their high protein, ability to grow on waste, and extra health benefits from compounds such as chitin. Success depends on matching the right ingredient and level to each fish species, careful processing, and supportive rules. By moving toward these sustainable options, the aquaculture industry can continue to supply healthy food while caring for the planet.

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Volume: 06 Issue No: 10

NATURAL FARMING: CHEMICAL FREE AND ON-FARM RESOURCE FARMING

Article ID: AG-VO6-I10-46

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Introduction

Natural Farming is a chemical-free farming system rooted in Indian tradition enriched with modern understanding of ecology, resource recycling and on-farm resource optimization. It is considered as agro ecology based diversified farming system which integrates crops, trees and livestock with functional biodiversity. It is largely based on on-farm biomass recycling with major stress on biomass mulching, use of on-farm cow dung-urine formulations; maintaining soil aeration and exclusion of all synthetic chemical inputs. Natural farming is expected to reduce dependency on purchased inputs. It is considered as a cost- effective farming practice with scope for increasing employment and rural development. Natural farming aims at restoring soil health, maintenance of diversity, ensure animal welfare, stress on efficient use of natural/local resources and promote ecological fairness. Natural farming is an ecological farming approach where farming system.

Aims and Objectives for Natural Farming promotion:

- Efficient utilization of land and natural resources (light, air, water)and preserve natural flora and fauna
- Restore soil health and fertility and soil's biological life
- Maintain crop diversity and its production
- Promote natural beneficial insects, animals and microbes in soil for nutrient recycling and biological control of pests and diseases
- Promotion of local breeds for livestock integration
- Use of natural / local resource-based inputs

- Reduce input cost of agricultural production and improve economics of farmers.

Importance of Natural Farming

Several studies have reported the effectiveness of natural farming in terms of increase in production, sustainability, saving of water use, improvement in soil health and farmland ecosystem. It is considered as a cost- effective farming practices with scope for raising employment and rural development. Natural Farming offers a solution to various problems, such as food insecurity, farmers' distress, and health problems arising due to pesticide and fertilizer residue in food and water, global warming, climate change and natural calamities. It also has the potential to generate employment, thereby stemming the migration of rural youth. Natural Farming, as the name suggests, is the art, practice and, increasingly, the science of working with nature to achieve much more with less.

Components of natural farming

Bijamrita : for seed treatment	
Jiwamrita :for Nutrient Management	
Mulching : for Micro climate management	
Waaphasa : for Water management	
Other component :	
Inter cropping : for crop management	

Benefits of Natural Farming

- **Environment Conservation:-**Natural Farming ensures better soil biology, improved agro-biodiversity and a more judicious usage of water with much smaller carbon and nitrogen footprints.
- **Ensures Better Health:-** As Natural Farming does not use any synthetic chemicals, health risks and hazards are eliminated. The food has higher nutrition density and therefore offers better health benefits.
- **Livestock Sustainability:-** The integration of livestock in the farming system plays an important role in Natural farming and helps in restoring the ecosystem. Eco-friendly bio-

inputs, such as Jeevamrit and Beejamrit, are prepared from cow dung and urine, and other natural products.

- **Reduced Water Consumption :-**By working with diverse crops that help each other and cover the soil to prevent unnecessary water loss through evaporation, Natural Farming optimizes the amount of 'crop per drop'.
- **Eliminates Application of Synthetic Chemical Inputs :-** The overuse of synthetic fertilizers, especially urea, pesticides, herbicides, weedicides etc. alters soil biology and soil structure, with subsequent loss of soil organic carbon and fertility.
- **Rejuvenates Soil Health :-** The most immediate impact of Natural Farming is on the biology of soil—on microbes and other living organisms such as earthworms. Soil health depends entirely on the living organisms in it.
- **Minimized Cost of Production:-**Natural Farming aims to drastically cut down production costs by encouraging farmers to prepare essential biological inputs using on-farm, natural and homegrown resources.
- **Increased Farmers' Income:-**Natural Farming aims to make farming viable and aspirational by increasing net incomes of farmers on account of cost reduction, reduced risks, similar yields, incomes from intercropping.
- **Employment Generation :-** Natural farming generates employment on account of natural farming input enterprises, value addition, marketing in local areas, etc. The surplus from natural farming is invested in the village itself.

Challenges of Natural Farming :

Despite its many advantages, natural farming faces some challenges:

- **Initial transition period –** farmers may experience lower yields initially as the soil adjusts to the new farming system.
- **Knowledge and training –** success in natural farming requires an understanding of ecological principles, which may necessitate farmer education.
- **Market demand and certification –** although demand for organic produce is growing, lack of certification and market access can hinder profitability.
- **Pest and disease management –** without synthetic pesticides, farmers must adopt alternative pest control strategies, which require experience and experimentation.

Conclusion

Natural farming is a promising agricultural practice that restores ecological balance while ensuring food security and environmental sustainability. By embracing nature's own mechanisms, farmers can cultivate healthier crops, reduce costs, and contribute to a more resilient planet. As awareness grows, more farmers, policymakers, and consumers are recognizing the significance of natural farming in shaping the future of sustainable agriculture.

Volume: 06 Issue No: 10

NON-CONVENTIONAL GREEN FODDER RESOURCES FOR LIVESTOCK

Article ID: AG-VO6-I10-47

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Introduction

Approximately 60–70% of the total expenditure on livestock farming is incurred on feed. Livestock feed is generally classified into three categories: green fodder, dry fodder and concentrate feed. Among these, green fodder production is insufficient to meet the requirements of livestock.

The increasing human population and the conversion of agricultural lands into residential areas have reduced the area available for cultivation. In addition, grazing lands and the area under green fodder production are declining. Consequently, providing adequate quantities of conventional green fodder to livestock has become increasingly difficult.

Natural calamities such as droughts, floods and cyclones further aggravate fodder shortages. These problems can be addressed by utilizing surplus agricultural crops, crop residues and other agricultural by-products that are readily available and often wasted.

Importance of non-conventional green fodder resources

Some non-conventional feed resources are rich in carbohydrates, while others contain considerable amounts of protein. Since these materials are often discarded without being utilized, they may be available at a low cost. Their effective utilization can reduce feeding expenses and lower the overall cost of livestock production. In many places, such materials are burned or dumped into water bodies, causing environmental pollution and potentially contributing to public health problems. Therefore, the productive utilization of non-conventional feed resources can help reduce environmental pollution, minimize waste and alleviate fodder shortages.

1. Sugarcane Tops

Sugarcane is cultivated extensively in Tamil Nadu, and sugarcane tops are a useful source of green fodder. However, they are relatively low in protein and contain approximately 65% moisture. Therefore, they should be supplemented with suitable protein-rich feed ingredients and other nutrients before being offered to livestock.

Sugarcane tops contain oxalates, which can interfere with calcium utilization. Hence, calcium supplementation may be necessary when feeding sugarcane tops in substantial quantities.

Sugarcane tops can be conserved as silage and used during periods of fodder scarcity. Ensiling helps preserve surplus fodder during periods of abundance for use during dry seasons. Properly prepared sugarcane-top silage has been reported to improve digestible crude protein and total digestible nutrients.

In addition to sugarcane tops, sugarcane bagasse and other by-products from sugar mills can also be incorporated into livestock feeding systems in suitable proportions.

2. Banana Plants

Banana is cultivated extensively in Tamil Nadu. Banana leaves, flowers and pseudostems can be used as livestock feed, particularly during periods of fodder scarcity.

Banana leaves contain vitamins, including vitamin A, and minerals such as calcium, making them useful supplementary feed resources.

Banana pseudostems and corms can be chopped into small pieces and fed to livestock. Chopping improves ease of consumption and helps reduce feed wastage by preventing animals from selectively consuming only the more palatable portions. It can also facilitate ingestion and digestion.

3. Papaya Plants

Papaya is cultivated in several states of India for its fruits and other useful products. The plant's leaves and stems can be chopped into small pieces and used as supplementary feed for livestock.

However, the outer bark of the stem is relatively hard and should be removed where necessary before feeding. The suitability and quantity of papaya plant material offered should be assessed carefully to ensure safe and balanced feeding.

4. Crop Residues

After harvesting crops such as maize, black gram and groundnut, substantial quantities of plant residues remain in the field. These residues can be utilized as livestock feed instead of being discarded.

In northern India, the leaves, stems and pods of mustard crops are also conserved and utilized during fodder-scarcity periods. Similarly, cotton and sunflower crop residues produced in our region can be processed, ground where appropriate, and mixed with other feed ingredients or concentrate mixtures for livestock.

Chopping crop residues into small pieces and incorporating them into properly formulated rations can help reduce feed wastage. Appropriate processing and supplementation are important because crop residues vary considerably in their nutritional value.

5. Vegetable Wastes

Large quantities of vegetable residues are generated during cultivation, processing, transportation and marketing. These materials can be collected and utilized as livestock feed when they are fresh, suitable and free from contamination.

Examples include:

- Potato leaves and stems left after harvesting.
- Outer leaves and discarded portions of cabbage and cauliflower.
- Leaves and residues of pulses and other field crops.
- Seed coats and other by-products from agricultural processing.

However, certain vegetable wastes, particularly cabbage and cauliflower residues, may contain relatively high concentrations of specific minerals such as molybdenum. Excessive intake can cause nutritional imbalances. Therefore, these materials should be fed in controlled quantities.

Pesticide residues may also be present in vegetable wastes because pesticides are widely used in vegetable cultivation. Consequently, such materials must be selected carefully and should not be fed if they are contaminated or suspected of containing unsafe pesticide residues.

6. Fruit Waste and By-products

Papaya fruit waste and other discarded fruit materials may serve as supplementary feed resources when properly collected and assessed for suitability.

Fruit-processing residues can provide useful nutrients and help reduce feed costs. However, their moisture content, nutrient composition, freshness and possible contamination should be considered before incorporating them into livestock rations.

7. Water Hyacinth

Water hyacinth is a fast-growing aquatic weed commonly found in ponds, tanks, lakes and rivers. It is generally unpalatable to livestock when offered fresh and untreated. However, it may be accepted more readily after suitable processing, such as drying.

Because water hyacinth can contain high levels of oxalic acid and other anti-nutritional substances, feeding fresh leaves directly may cause digestive disturbances, including diarrhoea.

Water hyacinth can also be incorporated into silage with suitable materials such as straw and mineral supplements. Its nutritional composition will depend on the processing method and ingredients used.

Water hyacinth can accumulate heavy metals and other pollutants from contaminated water. Therefore, it must not be used as livestock feed unless its source and safety have been established. Its controlled removal and appropriate utilization may help manage excessive growth and reduce obstruction of irrigation channels.

8. Arappu Tree

The Arappu tree is widely found in and around Tamil Nadu. Its leaves are consumed by cattle and goats, particularly when the leaves are young and tender.

However, the leaves are relatively less palatable, and livestock may consume only limited quantities. They can therefore be considered a supplementary feed resource rather than the sole source of green fodder.

9. Vathanarayanan Tree

The Vathanarayanan tree is found in several districts of Tamil Nadu, including Cuddalore, Villupuram, Perambalur, Ariyalur and Tirunelveli.

The leaves of this tree are consumed by goats and may be used as a supplementary feed resource where the plant is locally available. Its suitability and feeding quantity should be assessed before large-scale use.

10. Abandoned or Failed Crops

During natural calamities, particularly droughts and floods, certain crops may fail to grow properly or produce an economically viable yield. Instead of allowing these crops to go

completely to waste, they may sometimes be harvested and used as livestock feed. For example, when a standing paddy crop is severely affected by drought and is unlikely to produce a satisfactory grain yield, it may be harvested early and utilized as fodder, provided it is safe for livestock consumption.

Such utilization can help recover some value from failed crops and reduce fodder shortages during emergencies.

11. By-products from Agro-based Industries

Agricultural processing industries generate substantial quantities of by-products that can potentially be utilized in livestock feeding.

These include fruit peels, seeds, kernels and other residues from fruit-processing industries, as well as flower and leaf wastes from industries involved in the production of aromatic substances and essential oils.

The fruits and pods of certain trees, such as Prosopis species, along with mango kernels and other seasonal agricultural by-products, may also be useful supplementary feed resources when properly processed.

Similarly, subabul (Leucaena leucocephala) seeds and discarded tomato fruits may be utilized in suitable feeding systems, subject to appropriate processing, nutritional evaluation and safety assessment.

The effective use of these resources can help reduce conventional fodder requirements and minimize agricultural waste.

Precautions to Be Taken While Using Non-Conventional Feed Resources

The following precautions should be observed before introducing any new or non-conventional feed resource into livestock diets.

1. Identify the feed resource: Determine the type of plant or by-product, its botanical family and its nutritional characteristics.

2. Assess the presence of toxic substances: Investigate whether the material contains toxic compounds, anti-nutritional factors or other harmful substances.

3. Adopt appropriate processing methods: If toxic or anti-nutritional substances are present, identify suitable processing methods to reduce them and establish whether the material can be used safely as livestock feed.

4. Determine the safe feeding level: Establish the maximum quantity that can be offered without adversely affecting animal health, production or product quality.

5. Seek expert advice: Before using unfamiliar, potentially toxic or nutrient-rich plant materials, consult qualified veterinarians or animal nutrition specialists.

6. Maintain a balanced ration: Non-conventional feed resources should be incorporated into a nutritionally balanced diet rather than replacing all conventional feed ingredients indiscriminately.

7. Monitor animal health and performance: Observe feed intake, digestion, growth, milk production and other relevant indicators after introducing a new feed resource.

Conclusion

With the growing demand for food for both humans and livestock, it is essential to identify alternative feed resources that can reduce competition between human food and animal feed. Veterinarians, animal nutritionists, agricultural scientists and livestock farmers all have important roles in identifying, evaluating and utilizing non-conventional feed resources. By identifying suitable plant materials and agricultural by-products that are currently wasted, processing them appropriately and incorporating them into balanced livestock rations, farmers can reduce feeding costs and improve the profitability of livestock farming. The systematic utilization of non-conventional feed resources can contribute to better waste management, improved resource efficiency, reduced environmental pollution and greater feed security, particularly during droughts and other periods of fodder scarcity.

Let us utilize non-conventional feed resources!

Let us earn greater profits than through conventional feeding practices!

Volume: 06 Issue No: 10

ELECTRONIC LOGBOOKS: A SMART TOOL FOR SUSTAINABLE FISHERIES MANAGEMENT

Article ID: AG-VO6-I10-48

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Abstract

Fishing logbooks play a vital role in capturing information on fishing activities, fishing catch composition, fishing effort, vessel data, and fishing locations. Paper fishing logbooks have been traditionally used by fishers to capture data about their fishing operations as well as supply relevant information for the fisheries research and management purposes. However, paper logbooks may experience issues of errors in recording, incomplete information, and delayed data processing. The emergence of digital technology has led to the creation of e-logbooks that allow fishermen to record, store, and transmit their fishing data through smartphones, tablets, and computer-based systems. Electronic logging system can help enhance the speed and availability of fisheries data to support catch monitoring, stock assessment, and fisheries management. Combining both conventional and e-logbooks allows flexible data gathering in fisheries characterized by different level of accessibility of digital facilities. Nonetheless, some obstacles such as high cost of equipment, network coverage, user education, and data protection need to be addressed.

Keywords: Fisheries logbook, electronic logbook, catch and effort data, digital technology, fisheries monitoring, sustainable fisheries management.

Introduction

Fishing is an activity that plays a crucial role in contributing to food security, employment opportunities, livelihoods, and income generation of coastal populations. Management of fisheries resources needs accurate information about fishing activities, fish species composition, fishing efforts, fishing sites, and fishing vessels operations. Fisheries logbook is one of the ways of gathering fisheries data directly from fishing operations. It is considered an important method of collecting fisheries-dependent statistics.

Traditional fisheries logbooks refer to fisheries statistics that are paper documents. In most cases, such documents have data about fishing trips' dates, fishing vessel identity, fishing gear used, fishing time, fishing sites, fish species caught, number of catches, and by-catches. Such records can be used to calculate Catch per Unit Effort (CPUE). However, even though these tools prove to be helpful in many ways, there are a number of shortcomings with such logbooks. First, handwritten data may be hard to decipher; secondly, not all data may be gathered, and finally, conventional logbooks may get lost. Moreover, information recorded on paper should be entered in databases, which takes extra time and may result in mistakes while entering. Thus, to compensate for those problems, electronic logbooks were created. Using this kind of tool, fishers can input the data concerning catches and fishing activities through mobile applications, tablets, or computers. In different systems, depending on what kind of system is used, this data is verified, saved digitally, and sent to the appropriate organizations that monitor fishing.

Fisheries Logbook: concept and Significance

The fisheries logbook refers to the systematic documentation of the process of fishing by the fishers and their vessels. It contains details of inputs and outputs in fishing processes. As per the FAO's guidelines for logbooks and vessel monitoring systems, logbooks have significance not only for data collection but also for fisheries control.

The main information recorded in a fisheries logbook includes:

- Vessel information: Vessel name, registration number, vessel type, engine power, and crew details.
- Fishing-trip details: Departure date, duration of the trip, fishing dates, and landing date.
- Fishing gear information: Gear type, mesh size, net dimensions, number of hooks, and other gear-specific details.

- Catch composition: Species caught, quantity of each species, total catch, and fish size where recorded.
- Fishing effort: Fishing hours, number of sets or hauls, hooks deployed, or other effort measurements appropriate to the fishing method.
- Fishing location: Fishing-ground name, geographical coordinates, and depth of operation where available.
- Bycatch and discards: non-target species, incidental catches, and discarded fish.
- Operational and economic information: Fuel consumption, labor costs, gear expenses, and other details relevant to evaluating fishing performance.

These records help fisheries researchers estimate CPUE, examine fishing patterns, assess the performance of different fishing gears, and evaluate the economic efficiency of fishing operations.

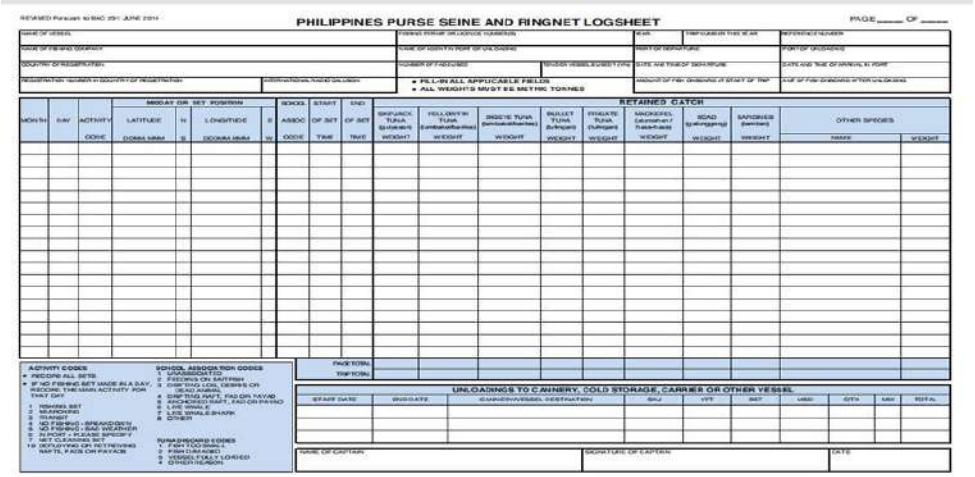

PHILIPPINES PURSE SEINE AND RINGNET LOGSHEET

Fig. 1.1: Traditional fisheries logbook: Traditional paper-based fisheries logbook used to record fishing trips, fishing effort, gear details, and catch composition.

Source: FAO, Logbooks and VMS.

Electronic Logbook: Technology and Applications

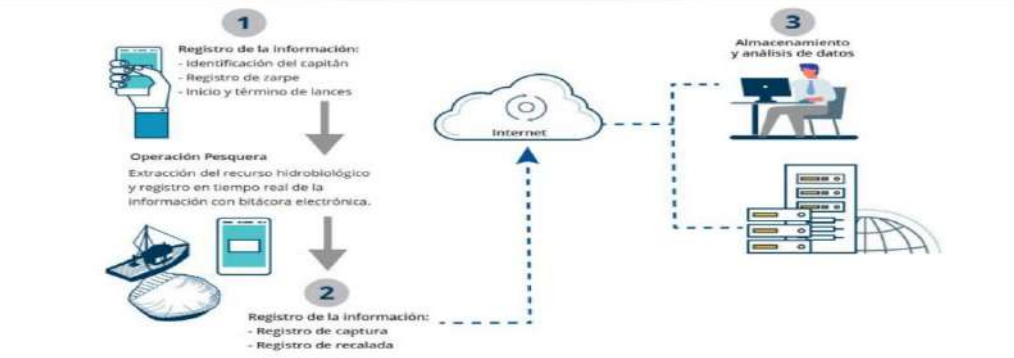
The electronic logbook, also known as the e-logbook, refers to a digital device for recording and uploading information related to fishing activities. This may run on a cell phone app, tablet, computer or an onboard machine. Electronic reporting systems have been implemented in some of the fisheries to gather information from fishing boats and upload this information to fisheries management authorities.

Electronic logbook devices allow creating digital forms for recording vessel information, fishing dates, fishing gears, catch amounts, fishing efforts, and any bycatches. Automated validation, digital record keeping, and electronic reporting are other functionalities that may be included in some of the electronic logbook devices. The capability of GPS is also included in some of the electronic logbooks though it does not exist in all the electronic logbooks.

Mobile-based reporting apps in the case of small-scale fisheries help in easier recording of catch and effort information. In the case of commercial longline fisheries, some of the digital logs may include the hook amount deployed, bait type, targeted species, bycatch, fishing time, and fishing location. Such information can help in calculating CPUE and comparing fishing efficiency. e-logbook is different from an electronic monitoring system. The e-logbook collects data input either manually or automatically by fishers, while electronic monitoring may use cameras, sensors, and other equipment to collect data about fishing activities. The two methods can be used together if correctly designed. Electronic logbooks can improve the speed and accessibility of fisheries reporting, but their effectiveness depends on system design, data quality, training, and appropriate implementation.

Fig. 1.2: **Electronic Fisheries Reporting Workflow**: Fishing information is entered into a mobile device, stored electronically, and transmitted to a reporting system for monitoring and analysis.

Source: WWF Chile — Electronic Fishing Logbook.



Integration of Fisheries and Electronic Logbooks

Integration of traditional and electronic logbooks implies keeping records on fishing while making use of digital tools to enhance processing of data. In places where facilities for going digital are not abundant, fishers could keep paper records that could afterwards be converted into

digital ones by the respective people. Where appropriate equipment is available, it becomes possible to enter data digitally.

Such an integrated system could employ standardized fields to collect information on vessel, fishing dates, gears, catch, fishing effort, and other data to be recorded. Then the data could be checked for accuracy, stored in a database, and analyzed to conduct studies on fishing. For instance, information could be collected on the number of hooks employed, bait used, fishing duration, targeted species, any by-catch, and fuel consumption of a motorized boat engaged in fishing of tuna longline. This information could be recorded in a paper logbook or electronic application. It would then become possible to calculate CPUE, assess gear performance, costs of fishing, and fuel efficiency. The FAO recommends considering logbooks as part of a broader information system that can include landing declarations, sales records, and vessel monitoring information. Integrating these sources can improve the interpretation and verification of fishing activity.

Benefits for Sustainable Fisheries Management

Improved fisheries data collection

Logbooks provide structured information on catch, effort, gear, and fishing operations. Electronic reporting can reduce manual transcription and make records available more

Catch per unit effort analysis

Logbook records enable researchers to calculate catch per unit effort using an appropriate effort measure, such as kilograms per fishing trip, kilograms per fishing hour, or kilograms per 1,000 hooks. CPUE can help compare fishing performance over time, although changes in catchability and fishing conditions must be considered when interpreting trends.

Fisheries stock assessment

Catch and effort records can contribute to stock assessments when combined with appropriate biological information, scientific surveys, and other reliable datasets. Such information supports the evaluation of fish-stock status and the development of management measures.

Monitoring and regulatory compliance

Logbooks help document fishing activity and can support compliance monitoring when combined with landing records, vessel monitoring systems, and other verification methods. They

can contribute to efforts to detect illegal, unreported and unregulated (IUU) fishing, but logbooks alone cannot establish that all reported information is accurate.

Economic evaluation

Recording fuel use, labour, gear expenses, fishing duration, and catch value helps researchers assess fishing costs, profitability, and operational efficiency. These records are particularly useful for comparing different fishing gears and vessel categories.

Traceability and responsible fishing

Consistent records of catch composition, fishing dates, and landing information can support seafood traceability and improve transparency in the fishing supply chain. When combined with effective verification systems, they can contribute to responsible fisheries management.

Challenges and Limitations

There are different yet at times overlapping challenges for traditional logbooks and electronic logbooks. For example, traditional logbooks might include inadequate information, inconsistencies in species name, poor handwriting, as well as transcription errors. Also, traditional logbooks may suffer loss and damage, thus making the archiving process problematic. Electronic logbooks require the cost incurred through purchasing of equipment, software, maintenance, and training. Limited availability of networks in remote fishing grounds will mean delayed entry of the information into the electronic logbook system, whereas lack of familiarity with the use of technology will be another issue. Data protection is also an issue for electronic logbook because of commercially sensitive information such as fishing grounds and operations contained within the logbook. Additionally, the use of electronic logging does not always ensure the accuracy of data recorded in the database.

Future Perspectives

The future evolution of fisheries logbook systems might be marked by increasing use of mobile applications, global positioning systems, cloud computing, monitoring technology, and automated data processing. These tools may facilitate better organization of fisheries and improve reporting capabilities if they are applied efficiently.

As far as small-scale fisheries are concerned, mobile applications that do not require internet access and user-friendly interfaces will be useful for fishers. Regarding the tuna longline fisheries, an online logbook may include the number of hooks, types of baits, the species fished,

bycatch, fishing time, and fuel consumed. It would help to analyze the effectiveness of fishing and related costs. Moreover, integration of online systems with vessel monitoring systems and electronic monitoring systems on board may contribute to collecting additional data. Nevertheless, technology is supposed to facilitate standardized procedures and scientific surveys rather than replace them. Future systems should ensure affordability, data validity, security, compatibility, and other benefits.

Conclusion

Fishery logbooks and electronic logbooks can be important instruments in documenting and analyzing fishing activities. While logbooks have the advantage of being an easy and inexpensive means of documenting catches and efforts, the use of electronic logbooks can ensure better data management and reporting. The use of the two methods is therefore a feasible strategy towards improving the management of fisheries data among various fishing sectors. It may not be easy to resolve the issues of cost of implementation, lack of connectivity, quality of data and training but the right technology and involvement of fishers can lead to accurate and useful fisheries records.

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Volume: 06 Issue No: 10

GREEN FOOD SUPPLY CHAINS: A SUSTAINABLE JOURNEY OF FOOD FROM FARM TO FORK

Article ID: AG-VO6-I10-49

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Introduction

Every day, food moves from farms through collection centres, processing units, warehouses and markets before reaching consumers. This journey requires considerable energy, water, fuel and packaging, often resulting in food waste, greenhouse gas emissions and resource depletion. With climate change and growing food demand, making these supply chains more sustainable has become essential. A green food supply chain focuses on reducing environmental impacts at every stage, from raw material sourcing and processing to storage, transportation, packaging and waste management, without compromising food quality or economic viability. Energy-efficient drying, renewable-powered cold storage, sustainable packaging and the conversion of processing by-products into useful products are some of the approaches gaining importance. Agricultural Process Engineering supports this transition through improved processing methods, efficient refrigeration, resource conservation and waste valorisation. In India, greener food supply chains can help reduce post-harvest losses, improve farmer incomes and support rural development. The goal is to deliver food from farm to fork more efficiently while conserving resources, minimising waste and protecting the environment.

What is Green Food Supply Chain?

A conventional supply chain focuses on moving products from suppliers to consumers, whereas a green supply chain also considers the environmental impact of every stage. For example, food industries can choose packaging that uses fewer materials and is recyclable, while transport operators can reduce fuel consumption through efficient route planning and better

vehicle utilisation. The Food and Agriculture Organization (FAO) emphasises resource efficiency, sustainable processing and distribution, and greener trade as important aspects of sustainable agrifood supply chains.

A green food supply chain involves five major components:

- Green sourcing: Procuring raw materials responsibly and promoting sustainable farming practices.
- Green processing: Saving energy and water, reducing pollution and improving production efficiency.
- Green storage and transportation: Maintaining product quality through efficient cold storage and optimised logistics.
- Green packaging and distribution: Minimising packaging waste while ensuring food safety and shelf life.
- Green recovery and waste management: Converting suitable agricultural residues, processing by-products and discarded materials into useful products.

These components are closely connected. For instance, reducing packaging weight may lower transport emissions, but inadequate protection can increase food spoilage. Similarly, refrigeration consumes energy but helps prevent losses of perishable produce. Therefore, a green supply chain requires an integrated approach that balances environmental protection, food quality and economic efficiency throughout the journey from farm to consumer.

Why Do Food Supply Chains Need to Become Greener?

Food supply chains consume large amounts of energy, water and fuel while generating waste and greenhouse gas emissions. According to the Food and Agriculture Organization (FAO), agrifood systems produced approximately 16.2 billion tonnes of CO_2-equivalent emissions in 2022, accounting for about 29.7% of global anthropogenic emissions. These figures include emissions from farming, land-use change, processing, transport, retail and food disposal. Improving the efficiency of activities beyond the farm is therefore essential for reducing the environmental impact of food production. A comparison between conventional and green food supply chain is shown below (Fig 1).

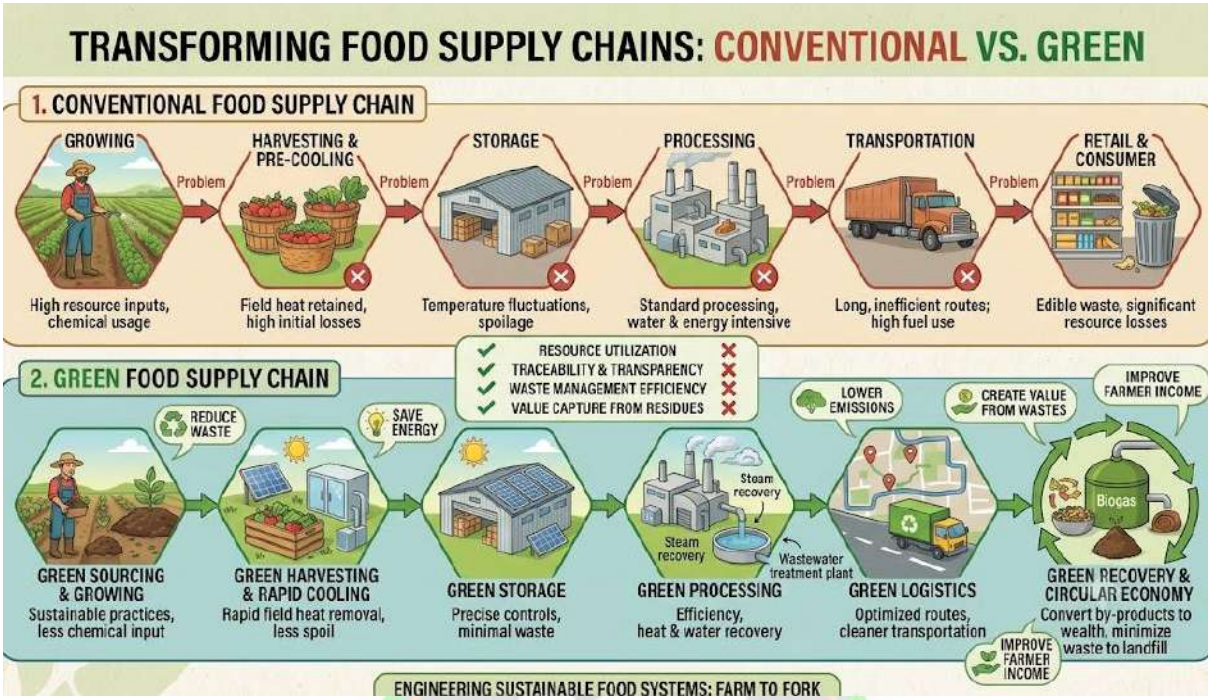


Fig 1. Comparison of Conventional and Green Food Supply Chain

Energy Consumption and Greenhouse Gas Emissions

Food industries require energy for drying, milling, refrigeration, heating, cleaning and packaging, while transportation and storage add to this demand. Energy-efficient motors, improved insulation, heat recovery and renewable electricity can reduce fuel consumption and emissions while lowering operating costs.

Food Loss and Waste

Food is often lost during harvesting, handling, storage, transportation and processing, while additional waste occurs in shops, restaurants and households. Such losses also waste the land, water, fertilisers, labour and energy used to produce food. Better storage, careful handling and efficient distribution can help preserve food quality and improve resource utilisation.

Water and Packaging Waste

Food processing requires water for washing, cooling, cleaning and manufacturing. Efficient equipment, leak prevention and suitable wastewater treatment can reduce freshwater demand. Similarly, excessive packaging increases material consumption and waste. Green supply chains aim to use water responsibly and select packaging that protects food while minimising environmental impacts.

Green Processing: Making Food Industries More Efficient

Agricultural Process Engineering helps food industries reduce resource consumption through improved equipment and process design. Energy-efficient machinery, renewable energy, better process control and resource recovery can improve productivity while reducing environmental impacts.

Energy-Efficient Drying

Drying is widely used to preserve grains, spices, fruits and vegetables, but conventional systems can consume considerable energy. Solar-assisted dryers and heat-pump dryers can reduce dependence on conventional fuels, while microwave-assisted drying may improve processing efficiency for suitable products. Sensors that monitor temperature, humidity and moisture content can help avoid unnecessary drying time. The most suitable technology depends on product quality, energy consumption, investment and operating conditions.

Waste-Heat Recovery

Food-processing plants often release usable heat through exhaust air, hot water and refrigeration systems. Heat exchangers and heat pumps can recover some of this energy for other operations, such as preheating cleaning water. This reduces additional heating requirements, improves overall energy efficiency and may lower operating costs.

Water-Efficient Processing

Water consumption can be reduced through efficient washing systems, controlled sprays, leak detection and improved cleaning practices. Depending on wastewater quality, membrane filtration and biological treatment may allow water reuse for suitable purposes. However, hygiene and food safety must remain priorities, and water used in food products must meet the applicable quality standards.

Green Cold Chains: Preserving Food Efficiently

Cold chains maintain the quality and safety of perishable products such as milk, fish, meat, fruits and vegetables. However, refrigeration consumes energy, while inadequate cooling can lead to significant food losses. Sustainable cold chains seek to balance these concerns by maintaining appropriate temperatures while reducing energy consumption and refrigerant leakage.

Efficient Refrigeration and Insulation

Efficient compressors, suitable refrigerants, good insulation and regular maintenance can improve refrigeration performance. Cold rooms must maintain commodity-specific temperature and humidity conditions to prevent spoilage. Properly sealed doors, clean heat exchangers and timely repairs also help prevent unnecessary energy consumption and maintain consistent cooling.

Solar-Powered Cold Storage

Solar-powered cold storage offers an alternative for rural areas, particularly where electricity supplies are unreliable. Batteries or thermal energy storage can provide cooling when solar generation is low. The choice of system depends on local weather, cooling requirements, investment costs and the reliability of the electricity supply.

Integrated Cold-Chain Infrastructure in India

In India, the Integrated Cold Chain and Value Addition Infrastructure scheme under the Pradhan Mantri Kisan SAMPADA Yojana supports eligible facilities such as pre-cooling units, cold storage and refrigerated transportation. When designed and operated efficiently, this infrastructure can reduce post-harvest losses and improve the movement of produce from farms to markets.

Green Logistics: Moving Food with Lower Emissions

Poorly planned transportation increases fuel consumption, delivery time and the risk of food spoilage. Green logistics focuses on efficient route planning, better vehicle utilisation and reduced emissions. Digital tools can help identify shorter routes, coordinate deliveries and reduce empty return trips, while suitable crates and reusable containers can protect produce from damage and improve vehicle loading. Reusable packaging is beneficial only when its durability, cleaning requirements and return transport are considered. Electric vehicles may be suitable for some short-distance deliveries where charging facilities are available, while efficient refrigeration and good insulation remain essential for temperature-controlled transport.

Sustainable Packaging: Protecting Food with Less Waste

Packaging protects food from contamination and physical damage while supporting storage, transport and shelf-life extension. The challenge is to provide this protection without using excessive materials or creating unnecessary waste. Starch, cellulose, plant fibres, bagasse and other agricultural residues are being explored for bio-based packaging applications, although

bio-based materials are not necessarily biodegradable and some biodegradable materials require specific composting conditions. Lightweight and recyclable packaging can reduce material use, but it must remain strong enough to prevent food damage. Active packaging can help control moisture or oxygen, while intelligent packaging may indicate temperature exposure or changes in product quality. These technologies require appropriate testing and cannot replace established food-safety procedures.

Circular Supply Chains: Turning Waste into Wealth

A green supply chain also considers how agricultural residues and food-processing by-products can be put to productive use. Fruit peels, vegetable trimmings, rice husk, bran and other residues may be converted into animal feed ingredients, compost, biogas, biochar, fibres or valuable food ingredients, depending on their suitability. For example, fruit-processing waste can provide compounds such as pectin, while suitable organic residues can produce biogas through anaerobic digestion. Rice husk may serve as a biomass fuel or raw material for other products. Proper treatment and quality checks are essential before recovered materials are reused.

Industrial Symbiosis

Industrial symbiosis occurs when one enterprise uses another enterprise's by-products, waste heat or recovered resources as inputs. For example, organic residues from a food-processing unit may supply a biogas plant, while recovered nutrients can be returned to agriculture. Such arrangements can reduce disposal costs and create additional value, but they require reliable supplies, suitable infrastructure, quality control and coordination between participating businesses.

The Importance of Life-Cycle Thinking

A technology should not be considered environmentally friendly simply because it uses recycled materials or renewable energy. Life-cycle assessment evaluates environmental impacts from raw-material production and manufacturing to transportation, use and disposal. For example, reusable containers require cleaning and return transport, while some biodegradable packages need specialised treatment. Life-cycle thinking helps determine whether a solution genuinely reduces environmental impacts or simply shifts them from one stage to another.

Digital Technologies for Smarter Supply Chains

Digital technologies can improve the monitoring and management of food supply chains by providing timely information about product quality, equipment performance and resource

consumption. Internet of Things sensors can track temperature, humidity, energy use and other operating conditions, helping identify problems before they lead to product losses. Artificial intelligence can support demand forecasting, route planning and predictive maintenance, reducing overproduction, unnecessary travel and equipment breakdowns. Digital traceability systems, including blockchain-based platforms, can record a product's origin, processing history and movement through the supply chain. Their usefulness depends on accurate data and reliable verification, and they should complement sound engineering and management practices rather than replace them.

Challenges

Adopting green supply chains can be difficult for small food businesses because efficient equipment, renewable-energy systems and wastewater-treatment facilities often require substantial initial investment. Rural areas may also lack reliable electricity, cold storage, transport facilities and trained technicians. Farmers, processors, transport operators and retailers must work together to improve coordination and reduce avoidable losses. Shared infrastructure, financial support and technical training can make sustainable technologies more accessible. Businesses should monitor progress using indicators such as energy and water consumption per kilogram of product, food-loss rates, packaging use and greenhouse gas emissions. A practical starting point is to identify major sources of waste, improve equipment maintenance, optimise processing operations and adopt suitable resource-recovery methods. Monitoring results helps businesses identify successful measures and expand them over time.

Conclusion

Green food supply chains are essential for balancing economic growth with environmental sustainability. By adopting energy-efficient processing, improved cold storage, cleaner transportation, sustainable packaging and waste recovery, food industries can reduce losses and conserve resources. Agricultural Process Engineering supports this transition through advanced drying, efficient refrigeration, water-saving technologies and the conversion of agricultural residues into valuable products. In India, these practices can improve farmer incomes, strengthen rural enterprises and enhance food security. Achieving these benefits requires appropriate technologies, investment and cooperation across the supply chain. Ultimately, a green food supply chain aims to deliver safe, quality food from farm to fork while minimising waste, resource consumption and environmental impact.

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Volume: 06 Issue No: 10

APPLICATION OF 4D FOOD PRINTING

Article ID: AG-VO6-I10-50

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Introduction

Three-dimensional (3D) food printing, an emerging application of additive manufacturing, has transformed the way edible products are designed and produced by enabling the layer-by-layer deposition of edible materials based on digital models. This innovative technology involves depositing edible ingredients layer by layer and building a three-dimensional structure based on a digital model or design. 3D food printers already exist: they squeeze purées, doughs, chocolate or cheese through a nozzle to create intricate shapes that would be hard to make by hand. The evolution line of food printing is shown in the Fig. 1.

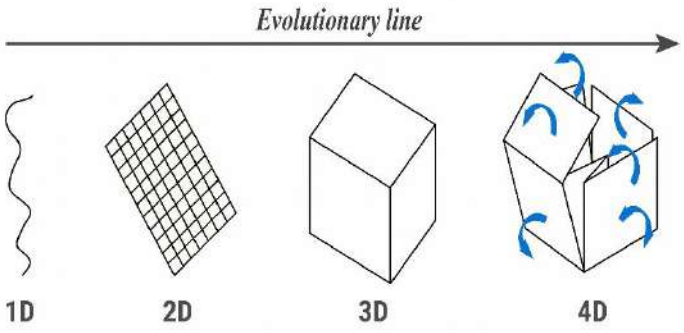


Fig. 1 Evolution line of food printing

4D food printing builds on standard 3D food printing by adding time as a fourth dimension. It uses smart, edible materials that change their shape, color, texture, flavor, or nutrient release over time after they are printed. A 4D-printed object is designed to change after it is printed, folding, bending, swelling or shifting colour in response to a trigger. The idea was popularised by MIT

researcher Skylar Tibbits around 2013 with printed materials that reshaped themselves in water. The comparison between 3D and 4D food printing were discussed in Table 1.

Table 1. 3D vs 4D Food Printing

Feature	3D Food Printing	4D Food Printing
Core Mechanism	Extrudes edible layers to build a final, static geometric shape.	Prints structures designed to autonomously change form, texture, or color *after* printing.
The "4th Dimension"	None. The printed object remains in its printed state until eaten or conventionally cooked.	Time. The food undergoes a pre-programmed, temporal transformation.
Base Materials	Standard pureed or meltable ingredients (chocolate, dough, plant-based proteins, cheese).	"Smart materials" and biopolymers with distinct, engineered expansion rates (e.g., specific ratios of gelatin, cellulose, and starch).
Response to Stimuli	Passive. Food reacts naturally to cooking (e.g., dough bakes, chocolate melts), but the core geometry is fixed.	Active and programmed. Internal structural stress forces the food to fold, bend, or morph when exposed to specific triggers like water, heat, microwave energy, or pH shifts.
Advantage	Intricate culinary customization, texture simulation for alternative meats, and precise portion control.	Massively reduced packaging volume (flat-packing), targeted drug/nutrient delivery, and dynamic flavor-release profiles.
Example	A complex sugar sculpture or customized pizza printed exactly as it will be served.	A flat sheet of dried pasta that physically curls into a complex tortellini shape only when dropped in boiling water.

Engineering Mechanics in 4D Food Printing

1. Smart Material Selection

Standard food purees don't naturally fold themselves. Engineers must formulate "smart inks" using food-grade hydrogels and biopolymers. Common materials include:

- Gelatin and Agar: Act as the base matrix because they easily absorb water and swell.
- Cellulose and Starch: Act as rigid, structural components that resist swelling.

- Ethylcellulose: A hydrophobic (water-repelling) material used to block moisture from entering specific areas.

2. Differential Swelling

The primary driving force behind 4D shape-shifting is differential swelling (also known as anisotropic expansion). If a piece of pasta absorbs water evenly, it just gets bigger. However, if an engineer prints a piece of pasta where one side absorbs water rapidly and the other side doesn't, the unequal expansion creates internal physical stress. Because the swelling side is getting larger while the other side remains rigid, the material is forced to bend or curl to relieve that stress.

3. Spatial Patterning (The "Code")

Engineers control how the food bends by carefully designing the internal structure and surface geometry before it is printed. They use Computer-Aided Design (CAD) to map out exactly where different materials should be deposited.

- Stripe Patterns: Printing rigid cellulose stripes across a gelatin base will cause the material to curl into a tube or spiral, much like traditional fusilli.
- Grid Patterns: Printing complex, multi-directional grids can force the flat sheet to buckle into saddle shapes or complex floral domes.

The thickness, spacing, and angle of these printed patterns dictate the exact final 3D geometry. The conceptual workflow of 4D food printing is shown in the Fig.2.

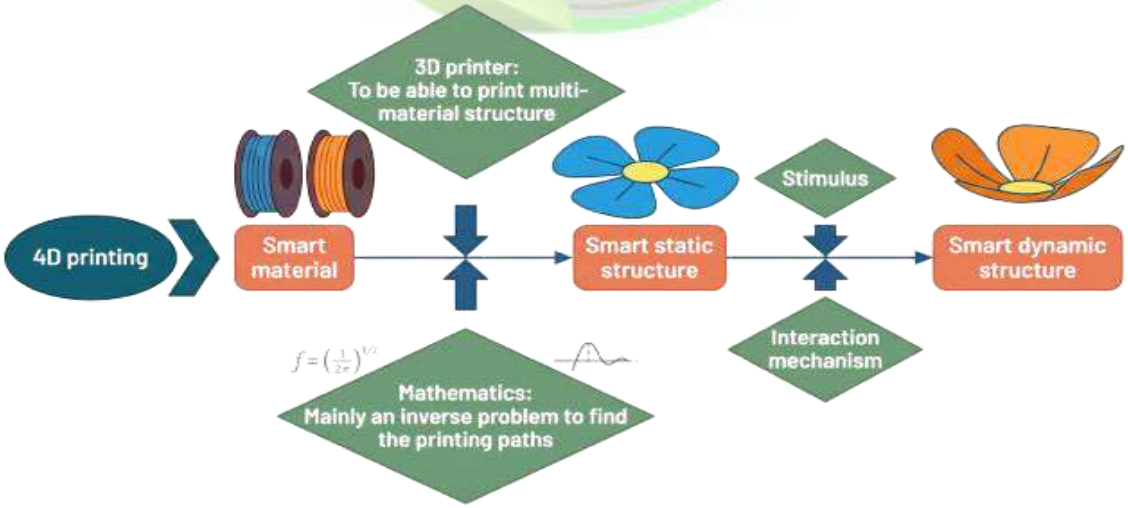


Fig.2. Conceptual Workflow of 4D Printing

4D Food Behaviours

Depending on the programmed smart ingredients, 4D food can achieve several mesmerizing behaviors beyond structural folding:

- Color Shifting: Cocktails or gelatins infused with anthocyanins (natural pigments found in red cabbage or butterfly pea flowers) that change from deep blue to bright pink when an acidic ingredient like lemon juice is added.
- Flavor Release: Flavor capsules or edible films engineered to dissolve at highly specific temperatures. A soup might taste completely different at 140°F than it does at 160°F as new waves of spice or umami are sequentially released.
- Texture Modification: Foods that soften drastically or change their mouthfeel based on the specific pH of human saliva, offering entirely new culinary experiences.

Potential Uses

- Smarter packaging and shipping: Flat food takes far less space than bulky shapes full of air. Pasta that ships flat and "blooms" when cooked could cut storage and transport costs and reduce packaging waste.
- Personalised nutrition. Because 3D printing builds food from a digital recipe, the nutrient content can be tailored to an individual's needs, such as extra protein for an athlete or controlled sugar for someone with diabetes. 4D features could add things like colour changes that signal a dish is ready or properly seasoned.
- Care for people with swallowing difficulties. Patients with dysphagia often eat unappealing puréed meals. Printed purées can be shaped to look like real food, and shape-changing designs could add texture or visual appeal while staying safe to swallow.
- Reducing food waste. Imperfect vegetables, by-products and surplus ingredients can be turned into printable pastes and made into appealing, high-value dishes.
- Culinary creativity. Chefs could serve dishes that transform at the table: a dessert that opens when warm sauce is poured over it, or a soup garnish that changes colour as the diner adds lemon.

Challenges

Despite its transformative potential, 4D food printing faces several significant hurdles before it can scale for the mass market. The most immediate bottleneck is speed, as current

printing technology remains painstakingly slow compared to the rapid output of industrial food manufacturing. Engineers are also constrained by strict material limits; every ingredient must delicately balance the ability to flow through a printer nozzle, maintain its structural integrity, respond predictably to environmental triggers, and still taste appealing. Furthermore, navigating safety and regulation is complex, requiring rigorous approval for new additives and processes to ensure consistent, food-safe results with every print. Combined with the prohibitively high cost of specialized printers and tailored "smart" recipes, the technology is currently expensive to scale. Ultimately, the industry must also win consumer acceptance by proving to a public often wary of highly engineered foods that these shape-shifting meals are not just scientifically impressive, but genuinely trustworthy, natural, and delicious.

Conclusion

4D food printing stands at the frontier of culinary science and advanced materials engineering, redefining how we conceive of food production, logistics, and consumption. By introducing the dimension of time, it transforms passive ingredients into dynamic, responsive systems capable of self-assembly, targeted nutrient delivery, and dramatic volume reduction. While technical hurdles ranging from slow print throughput and material rheology constraints to regulatory approval and consumer skepticism, must still be overcome, the foundational potential is undeniable. As biopolymer engineering matures and printing hardware scales, 4D food printing will transition from a high-tech novelty to a vital tool in sustainable supply chains, personalized healthcare, and the future of dining.

Volume: 06 Issue No: 10

VERMICOMPOST: TURNING ORGANIC WASTE INTO A VALUABLE RESOURCE FOR SUSTAINABLE AGRICULTURE

Article ID: AG-VO6-I10-51

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Abstract

Vermicomposting is a biological process in which earthworms and microorganisms work together to convert organic waste into nutrient-rich vermicompost. It offers an approach to organic waste recycling and has potential benefits for soil fertility and plant growth. Research has reported improvements in seed germination, root and shoot growth, biomass production, and crop yield following vermicompost application. A meta-analysis of 68 publications by Blouin et al. (2019) reported average increases of 26% in commercial yield, 13% in total biomass, 78% in shoot biomass, and 57% in root biomass. However, the effects of vermicompost are not uniform and may vary with its composition, the proportion used, and the crop grown. Different production systems, including batch systems, windrows, and continuous-flow vermireactors, have also been examined for organic waste conversion. Understanding these variations is important for the effective use of vermicompost in sustainable agriculture. This article highlights the vermicomposting process, its potential contributions to plant growth and soil fertility, production technologies, and the limitations identified in published research.

Keywords: Vermicompost, vermicomposting, earthworms, organic waste recycling, soil fertility, plant growth, sustainable agriculture, vermicomposting technologies

Introduction

Agriculture depends on healthy soil, adequate nutrients and active soil microorganisms for successful crop production. At the same time, agricultural, domestic and agro-industrial activities generate substantial quantities of organic residues. These residues contain materials that can be recycled rather than discarded. Vermicomposting is one biological process that

converts organic waste into a nutrient-rich product with potential applications in agriculture and horticulture. Vermicomposting involves the combined activities of earthworms and microorganisms in the decomposition and stabilization of organic materials. The resulting product, known as vermicompost, has attracted scientific interest because of its nutrient content, biological activity and reported effects on plant growth and soil properties. Research has investigated its use in vegetable production, field crops, horticulture and sustainable waste management.

However, vermicompost should not be considered a universally effective substitute for every fertilizer or soil amendment. Its effects depend on the materials used, the production process, the amount applied and the crop being grown. Understanding both its benefits and limitations is essential for its appropriate use in agriculture.

What Is Vermicomposting?

Vermicomposting is the biological processing of organic residues through interactions between earthworms and microorganisms. Microorganisms are primarily responsible for the biochemical breakdown of organic matter, while earthworms fragment, ingest and condition the material, creating conditions that influence further microbial decomposition. According to Lazcano and Domínguez, earthworms act as biological processors by fragmenting organic materials, increasing the surface area available to microorganisms and modifying the substrate's physical and chemical properties. Their activities influence microbial activity and contribute to the formation of a relatively uniform, stabilized material.

The final vermicompost is generally described as a finely divided, peat-like organic amendment with high porosity and water-holding capacity. Many of its nutrients occur in forms that plants can readily absorb. It also contains organic matter, microorganisms and biologically active substances associated with the decomposition process.

A variety of organic materials have been investigated for vermicomposting. These include agricultural residues such as rice husk, cereal residues and millet straw; animal manures; food-processing wastes; horticultural residues; and selected paper and wood-processing wastes. The suitability of a particular material depends on its characteristics and its compatibility with the earthworms and microorganisms involved., Rhizobium, Azotobacter, Bacillus, Pseudomonas or beneficial actinobacteria.

How Do Earthworms and Microorganisms Work Together?

Vermicomposting is not simply the action of earthworms or microorganisms operating independently. It is a biological process in which both contribute to the transformation of organic residues.

Initially, microorganisms present in the organic waste begin breaking down the material. Earthworms subsequently ingest and fragment the waste, improve its physical condition and distribute microorganisms through their activities. Microorganisms associated with the earthworm gut also contribute to the degradation of organic compounds by producing enzymes that break down substances such as cellulose, hemicellulose, proteins and lipids.

The earthworms' activities can improve aeration within the substrate and increase the surface area exposed to microbial action. The combined process supports the decomposition and transformation of organic residues into vermicompost.

The review by Enebe and Erasmus describes vermicomposting as a process involving microbial decomposition, earthworm burrowing and ingestion, followed by maturation. The duration and efficiency of processing vary with the type of organic material, earthworm species, population density, reactor design and environmental conditions.

Thus, the quality of vermicompost is influenced not only by the original waste but also by the biological and operational conditions under which it is produced.

What Does Scientific Research Say About Plant Growth?

One of the most important questions is whether vermicompost improves plant growth and crop yield. Numerous experiments have investigated its effects on seed germination, root and shoot development, flowering, biomass production and harvestable yield.

Lazcano and Domínguez reviewed studies reporting beneficial effects in a range of crops, including tomato, pepper, garlic, aubergine, strawberry, sweet corn, green gram, rice, sorghum, banana and papaya. Studies also reported responses in ornamental and forestry plants. These findings indicate that the potential applications of vermicompost extend beyond a single crop group.

Reported responses include increased seed germination, root branching, leaf area, shoot development, flowering and fruit production. Some studies have also investigated changes in the nutritional composition of vegetables and other plant products.

An important contribution to this field was made by Blouin and colleagues in their 2019 meta-analysis, titled "Vermicompost significantly affects plant growth." A meta-analysis combines results from multiple studies to estimate an overall effect rather than relying on a single experiment.

The researchers analysed 68 publications that met their selection criteria. Their results indicated average increases of:

1. 26% in commercial yield
2. 13% in total plant biomass
3. 78% in shoot biomass
4. 57% in root biomass

These percentages represent the averages reported across the studies included in the meta-analysis. They should not be interpreted as guaranteed increases for every crop, soil or farming situation. The researchers also discussed potential publication bias and differences among experimental studies.

The meta-analysis further showed that the response depended on the proportion of vermicompost in the growing medium, the original material used to produce it, the plant group and whether mineral fertilizer was also applied. Cattle manure was associated with the strongest overall effects among the original materials assessed in that analysis.

These results provide quantitative evidence that vermicompost can improve plant growth and yield under suitable conditions, while also demonstrating the importance of considering experimental conditions when interpreting the findings.

Vermicompost and Soil Fertility

Plant growth depends on more than the direct supply of nutrients. Soil physical properties, nutrient retention, water availability and biological activity also influence crop development. Vermicompost has been described as an organic amendment with high porosity and water-holding capacity. Its organic matter and physical characteristics can influence soil structure, while its nutrients contribute to plant nutrition.

Research reviewed by Lazcano and Domínguez indicates that the addition of composted materials can influence soil bulk density, water-holding capacity, soil organic carbon, nutrient availability, microbial biomass and enzyme activity. The authors also emphasize that the

biological properties of vermicompost differ from those of conventional compost, even when both are produced from the same original waste.

Theunissen and colleagues reviewed the potential of plant-waste-derived vermicompost in vegetable production. They described its nutrient content, including nitrogen, phosphorus, potassium, calcium, magnesium and several micronutrients. These nutrients contribute to plant nutrition and are involved in physiological processes associated with plant growth and development.

The review also discussed humic substances present in vermicompost. These substances have been investigated for their effects on root development, nutrient uptake and plant growth. Microorganisms and biologically active compounds associated with vermicompost may contribute to its observed effects, although the relative importance of individual mechanisms varies among studies.

Consequently, vermicompost should be understood as more than a source of nutrients. It is a biologically active organic amendment whose effects may arise from interactions among nutrient supply, organic matter, physical properties and biological processes.

Vermicomposting as a Waste-Management Technology

A major agricultural and environmental advantage of vermicomposting is its potential to recover useful resources from organic waste. The review by Margit Olle describes the use of vermicomposting for processing agricultural residues, food and animal wastes, horticultural residues and several agro-industrial materials. Such residues can contain nutrients and organic matter that may otherwise be lost through inappropriate disposal.

Vermicomposting therefore links waste management with agricultural resource recovery. Instead of treating suitable organic residues solely as waste, the process can transform them into an organic amendment that may be returned to soil. Enebe and Erasmus examined different vermicomposting technologies, including batch systems, windrows and continuous-flow reactors. Each system has operational advantages and limitations related to labour, space, processing time, earthworm management, harvesting and nutrient losses.

Their 2023 review concluded that continuous-flow vermireactors generally performed better in waste bioconversion than batch and windrow techniques in the literature they evaluated. The authors also highlighted the potential of compartmentalized composite-frame vermireactors for waste valorization. These findings concern the technologies assessed in the review and do not

establish that a single reactor design is optimal for every setting. The choice of system must therefore reflect the nature and quantity of available waste, the desired production scale, operating resources and the quality of the final product.

Why More Vermicompost Does Not Always Mean Better Growth

Despite the many positive findings, the scientific literature does not show that vermicompost produces the same response in every situation. Lazcano and Domínguez noted substantial variability among studies, including reports of reduced plant growth and, in some cases, plant death. The composition of the original waste, the characteristics of the finished vermicompost, the crop species and the proportion used in the growing medium can all influence the response.

Blouin and colleagues found that the positive effect on plant growth was greatest at intermediate proportions of vermicompost in the growing medium. Their analysis indicated a maximum positive response around 30–50% by volume for the overall effects examined, while higher proportions could reduce or eliminate some positive responses, particularly for root biomass.

This result must be interpreted within the context of their meta-analysis. It is not a universal application rate for field soils, all crops or all vermicompost products. The authors also stressed the need for better comparisons between conventional compost and vermicompost made from equivalent organic materials. Such comparisons are important for determining whether observed benefits arise specifically from earthworm processing or from the addition of organic matter more generally.

Theunissen and colleagues similarly emphasized that the nutrient composition of vermicompost depends on the material from which it is produced. Consequently, the product's quality cannot be assumed to be identical across different feedstocks. These findings highlight the importance of appropriate production, assessment of the finished product and crop-specific evaluation before vermicompost is used extensively.

Conclusion

Vermicomposting represents a biological approach to converting suitable organic residues into a potentially valuable agricultural resource. Its scientific importance lies in the combined action of earthworms and microorganisms, the recovery of nutrients from organic waste and the reported effects on plant growth and soil properties.

Published studies have documented improvements in plant biomass and commercial yield, while reviews have described its potential contributions to nutrient availability, soil physical properties and microbial activity. The 2019 meta-analysis by Blouin and colleagues provides quantitative evidence of average positive effects across the studies evaluated.

Nevertheless, the effects of vermicompost vary with its composition, production technology, application proportion and crop. Excessive proportions may reduce some growth responses, and further comparisons are needed to establish its performance relative to other organic amendments under equivalent conditions.

The scientific evidence therefore supports vermicomposting as a promising component of sustainable agriculture and organic-waste management, provided that its production and use are guided by the characteristics of the material and the conditions of cultivation.

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Volume: 06 Issue No: 10

WHEAT BLAST: UNDERSTANDING THE DISEASE, TRACKING ITS SPREAD AND EXPLORING RESISTANCE IN WHEAT

Article ID: AG-VO6-I10-52

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Abstract

Wheat blast, caused by *Magnaporthe oryzae* Triticum pathotype (MoT), is a serious fungal disease that threatens wheat production. First reported in Brazil in 1985, the disease was reported in Bangladesh in 2016, raising concerns about its potential spread to other wheat-growing regions. The disease primarily affects wheat spikes, causing premature bleaching, sterility and poorly developed grains, with severe yield losses under favourable conditions. Research has examined different aspects of wheat blast, including disease epidemiology, the production of fungal spores on basal wheat leaves, climate suitability, pathogen identification and the development of resistant wheat material. Cruz et al. (2015) demonstrated that basal wheat leaves can produce large numbers of fungal conidia, while Gupta et al. (2020) developed methods for isolating, characterizing and detecting the pathogen in Bangladesh. A study by Harun-Or-Rashid et al. (2019) investigated gamma irradiation as a means of identifying wheat material with reduced disease incidence and severity. Climate-based modelling by Cruz et al. (2016) also highlighted potential areas of disease risk in the United States. Together, these studies demonstrate the importance of understanding pathogen biology, improving surveillance and evaluating resistance. However, promising experimental findings require further validation before they can be translated into reliable disease-management practices.

Keywords: Wheat blast, *Magnaporthe oryzae* Triticum pathotype, disease epidemiology, gamma irradiation, disease resistance, pathogen detection, conidia, wheat disease management

Introduction

Wheat is an important cereal crop, and diseases affecting its production can threaten grain yield and quality. Among these diseases, wheat blast has attracted considerable attention because of its potential to cause severe damage under favourable environmental conditions. The disease is caused by the Triticum pathotype of the fungus *Magnaporthe oryzae*, commonly abbreviated as MoT. It is also referred to as Pyricularia oryzae Triticum pathotype in the scientific literature.

Wheat blast was first reported in the Brazilian state of Paraná in 1985. Subsequently, it was reported in other South American countries, including Bolivia, Paraguay and Argentina. In February 2016, the disease was reported in Bangladesh, marking its emergence outside South America and raising concerns about the movement of the pathogen through infected seed or grain (Cruz and Valent, 2017).

The importance of wheat blast lies in its capacity to damage wheat spikes during critical stages of crop development. Infection may result in premature bleaching of the spike, partial or complete sterility and shrivelled grains. The extent of damage depends on factors such as the susceptibility of the wheat cultivar, the timing and location of infection, and environmental conditions.

Research on wheat blast has therefore expanded beyond symptom identification to investigate how the pathogen spreads, survives, produces inoculum and can be detected. Scientists have also examined approaches for identifying wheat material with reduced disease susceptibility. The findings from these studies provide useful insights into the challenges of understanding and managing this disease.

Recognising Wheat Blast: Symptoms and Crop Damage

The most characteristic symptom of wheat blast is the premature bleaching of the wheat spike. Depending on where the fungus infects the spike, bleaching may affect part or all of it. Infection of the rachis or peduncle can interfere with the movement of photosynthates to the developing grains, resulting in partial or complete spike sterility.

Infected grains may be small, shrivelled, deformed and of low test weight. The greatest yield losses have been associated with infections beginning during flowering or early grain formation. Under favourable conditions, susceptible cultivars may experience extremely severe losses, although the actual damage varies among locations and seasons (Cruz and Valent, 2017).

Although wheat blast is primarily recognised as a spike disease, the fungus can also infect other above-ground plant parts. Lesions may develop on leaves and stems, and sporulation can occur on lower, ageing leaves. However, visible leaf symptoms are not always prominent in severely affected commercial fields.

Recognising the disease requires attention to the characteristic bleaching of spikes and other symptoms, while also considering that spike bleaching alone is not sufficient to establish a definitive diagnosis. Reliable identification of the causal pathogen is important for research and disease surveillance.

Beyond the Spike: Basal Leaves as a Potential Source of Infection

A study by Cruz et al. (2015) investigated whether basal wheat leaves could contribute to the inoculum responsible for wheat blast epidemics. Before this work, the importance of fungal spores produced on wheat leaves in the development of spike blast remained uncertain.

The researchers found that certain combinations of wheat cultivars and fungal isolates produced more severe disease on older leaves than on young, expanding leaves. They also demonstrated that M. oryzae could sporulate on basal leaves of adult wheat plants under greenhouse and field conditions.

Under favourable conditions for sporulation, the researchers recorded an average of 1,669,000 conidia per gram of dry basal leaves of a highly susceptible cultivar. This finding showed that basal leaves could support substantial production of fungal spores.

The study also evaluated foliar fungicide applications under natural epidemic conditions. Fungicide-treated plots had 62–77% fewer conidia on basal leaves than unsprayed controls. The authors suggested that earlier fungicide applications might reduce inoculum if spores from basal leaves contribute to spike blast development.

However, the study did not establish that basal-leaf inoculum is responsible for all spike infections. The epidemiological role of these spores requires further investigation. The findings nevertheless highlight the importance of examining the entire wheat canopy when studying disease development rather than focusing exclusively on infected spikes.

Identifying the Pathogen: The Role of Laboratory Diagnostics

Accurate identification of the causal organism is essential for understanding disease outbreaks and conducting research on management strategies. This is particularly important

when closely related fungal pathotypes may have similar cultural and morphological characteristics.

Gupta et al. (2020) investigated suitable methods for isolating, culturing, storing and identifying MoT isolates collected from wheat blast-affected fields in Bangladesh.

The researchers developed a modified monoconidial isolation technique to obtain fungal isolates from infected plant material. They also established a method for producing abundant conidia for pathogenicity studies and described a dry-filter-paper method for storing the isolates.

Their work demonstrated that molecular techniques could complement morphological examination. The researchers used M. oryzae-specific primers, including Pot2-related primers, and MoT-specific MoT3 primers to identify the pathogen. They also established a PCR-based detection approach for infected leaf and seed samples.

The study reported that the Bangladeshi isolates examined had similar cultural and morphological characteristics and were consistent with a single clonal lineage. The developed methods were intended to support pathogen surveillance, further biological studies and the development of disease-management strategies.

These findings illustrate how reliable laboratory methods can strengthen disease investigations. Nevertheless, diagnostic results depend on the suitability of the method and the material being tested; molecular identification and field observations serve complementary purposes.

Gamma Irradiation: Exploring Wheat Material with Reduced Disease Susceptibility

Developing wheat material with improved resistance is an important research direction for wheat blast management. Harun-Or-Rashid et al. (2019) investigated gamma irradiation as a method for identifying wheat material showing reduced disease incidence and severity.

In the study, seeds of three wheat varieties—BARI Gom-25, BARI Gom-29 and BARI Gom-30—were exposed to gamma radiation doses of 150, 200, 250 and 300 Gy using a cobalt-60 source. The irradiated seeds were subsequently grown in farmers' fields in Chandbil, Meherpur Sadar, a wheat blast-prone area of Bangladesh.

The researchers reported significant differences in disease incidence and severity among irradiation treatments. The 200 Gy and 250 Gy treatments performed better than the untreated control in reducing disease in the varieties evaluated.

The lowest reported disease incidence was 17.33% in BARI Gom-29 following treatment at 250 Gy. The lowest reported disease severity was 42.33% in BARI Gom-25 following treatment at 200 Gy. The authors identified BARI Gom-30 as the best-performing variety overall among the three evaluated, followed by BARI Gom-25 and BARI Gom-29.

The researchers also used PCR with a specific primer to investigate the presence of MoT in infected spike samples. A 350-base-pair amplification product was observed in nine of the reported M2 family samples. The authors noted that further molecular analysis using additional primers and real-time PCR would be useful.

Importantly, the study recommended advancing the selected mutant lines to the M3 generation and evaluating them through artificial inoculation. Thus, the results should be understood as preliminary evidence supporting further resistance screening, not as proof that a fully resistant wheat variety has already been developed. Additional generations of selection and testing are necessary to establish the consistency of the observed response.

Climate Suitability and the Risk of Disease Spread

Understanding where a pathogen could establish and cause disease is another important part of plant disease research. Cruz et al. (2016) used weather-based models to assess the climate suitability of MoT in the contiguous United States.

The researchers considered three components of the disease cycle: inoculum buildup before wheat heading, infection during the heading stage and survival of the pathogen through winter. Their models incorporated temperature, leaf-wetness duration, precipitation and conditions associated with overwintering survival.

The results suggested that climatic conditions could support pathogen establishment in parts of the United States, particularly in some southeastern areas. Using the thresholds selected for the analysis, the models indicated that the climate could support pathogen establishment in areas representing approximately 40% of winter wheat production regions, while outbreak thresholds were reached in approximately 25% of the country. Louisiana, Mississippi and Florida were among the states where the estimated probability of suitable outbreak years exceeded 70%.

These estimates were based on climate models and should not be interpreted as confirmation that MoT was present or that outbreaks would necessarily occur in the identified areas. The authors presented the modelling results as a foundation for more advanced risk assessment and for prioritising research on pathogen biology and disease epidemiology.

The study also emphasised the relevance of seed or grain movement because the pathogen is seedborne. Together, climate modelling and pathogen surveillance can help researchers assess potential risks, while recognising that climatic suitability alone does not establish disease occurrence.

Understanding Disease Spread and Remaining Challenges

Cruz and Valent (2017) reviewed the emergence and spread of wheat blast and identified several challenges that complicate its management. The movement of infected seed or grain is a potential pathway for long-distance dispersal. The pathogen's capacity to produce spores and infect susceptible wheat under favourable conditions also contributes to concern about disease spread.

The review highlighted the need to identify additional sources of resistance and improve understanding of MoT ecology and disease epidemiology. It also discussed pathogen variability and the potential importance of genetic changes that could affect host interactions.

The research discussed in the five papers approaches these challenges from different perspectives. Studies of basal-leaf sporulation investigate possible sources of inoculum within wheat crops. Diagnostic research improves the ability to identify the pathogen. Gamma-irradiation experiments investigate possible sources of reduced disease susceptibility, while climate-based models assess potential environmental suitability for disease establishment and outbreaks.

These approaches provide complementary information, but they do not remove the need for further research. In particular, the role of basal-leaf inoculum in spike infection requires clarification, candidate mutant wheat lines require further evaluation, and climate-risk predictions must be interpreted within the limits of the models used.

Conclusion

Wheat blast is a serious fungal disease whose impact depends on pathogen characteristics, wheat susceptibility and environmental conditions. Research has improved understanding of its symptoms, potential sources of inoculum, laboratory identification and possible geographical spread. Experiments on gamma-irradiated wheat have also identified treatments associated with reduced disease incidence and severity in the varieties examined.

The available findings do not support a single solution that can be assumed to work under all conditions. Instead, they highlight the value of combining reliable pathogen identification,

improved understanding of disease epidemiology, careful evaluation of potentially resistant wheat material and evidence-based risk assessment. Continued validation of experimental findings will be essential before promising research results can be translated into dependable wheat blast management strategies.

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Volume: 06 Issue No: 10

RAPID DETECTION OF FOOD ADULTERANTS USING ADVANCED ANALYTICAL AND SPECTROSCOPIC TECHNIQUES

Article ID: AG-VO6-I10-53

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Abstract

Food adulteration impacts everything from milk and meat to olive oil, honey, and saffron. It is the deliberate addition, dilution, or replacement of constituents with less expensive or dangerous substances. Although accurate, wet-chemical and chromatographic techniques are slow, expensive, and limited to specialized labs. Near-infrared, Raman, mid-infrared, ultraviolet-visible, and fluorescence spectroscopy, hyperspectral imaging, portable equipment, confirmatory techniques, and chemometric and machine-learning technologies are all covered in this chapter. Standardization and calibration transfer are still unsolved, despite reported accuracy rates for oils, dairy products, spices, and meat frequently above 95%. The most practicable method of authentication is portable screening supported by laboratory confirmation.

Keywords: Food adulteration; food authentication; spectroscopy; hyperspectral imaging; chemometrics; portable sensors

1. Introduction

Almost every food category is affected by adulteration, from high-value items like extra virgin olive oil (EVOO), honey, and saffron to essentials like milk, meat, and grains. For example, Sudan dyes in spices and melamine in milk products have been connected to toxicity (Sreenivasulu, 2025). Because adulterants imitate genuine composition and supply networks span multiple countries, detection is challenging. While spectroscopy, spectral imaging, and multivariate statistics provide quick, mostly non-destructive alternatives, wet chemistry and chromatography are accurate but laboratory-bound and slow (McVey et al., 2021).

2. Principles of Spectroscopic Authentication

Because authentic and contaminated items have distinct chemical compositions, they interact with electromagnetic radiation differently, which is the basis for spectroscopic authentication (Moghaddam et al., 2022). Overtones and combination bands of C-H, O-H, and N-H vibrations are recorded by near-infrared (NIR) spectroscopy (780-2500 nm). Although it depends on calibration models and is influenced by moisture, band overlap, and particle size, it is quick and requires little preparation. NIR screening identified Sudan I–IV and Para Red in paprika with sensitivity and specificity above 90% (Trentanni Hansen et al., 2019), and portable devices measured black cumin oil adulteration (Menevseoglu, 2022).

Fused machine-learning algorithms detected dairy brands with 99% accuracy using Raman spectroscopy, which measures inelastic scattering and reacts strongly to non-polar groups in lipids and carotenoids (Feng et al., 2024). Fundamental mid-infrared vibrations (4000-400 cm^{-1}) are detected by Fourier transform infrared (FTIR) spectroscopy. FTIR and ultraviolet-visible (UV-Vis) spectroscopy categorized samples with 99.8% and 99.6% accuracy, respectively, for EVOO contaminated with less expensive oils (Malavi et al., 2023). At a 10% limit, fluorescence identified soybean and maize flours in Arabica coffee (Xie & Tan, 2022).

3. Hyperspectral Imaging

Each pixel in hyperspectral imaging (HSI) captures hundreds of consecutive spectral bands. While HSI maps the location and concentration of adulterants, a standard spectrometer only provides an average spectrum and may overlook adulterants that are irregularly distributed. NIR-HSI categorized EVOO contaminated with lower-grade and hazelnut oils with 93.9–100% accuracy at levels as low as 1% (Malavi et al., 2024), while visible-NIR HSI using machine learning identified chicken in minced beef non-destructively (Kamruzzaman et al., 2016).

4. Confirmatory Methods and Portable Devices

The standard for verifying quick methods is still separation techniques. Isotope ratio mass spectrometry confirms geographical origin, and chromatography profiles phenolics and tocopherols that distinguish EVOO from lower-grade oils (González-Pereira et al., 2021). EVOO was classified with 93.7% accuracy using gas chromatography-mass spectrometry (GC-MS), which is less accurate than spectroscopy but helpful for verifying questionable samples (Malavi et al., 2023). For species identification in foods derived from animals, DNA-based techniques are frequently the norm (Abbas et al., 2018), and benchtop ultrafast 2D NMR at 43 MHz is less

expensive to operate than high-field instruments (Gouilleux et al., 2018). Handheld spectrometers and miniature mass spectrometers now deliver results at the sampling site (McVey et al., 2021; Gerbig et al., 2017).

5. Chemometrics and Data Fusion

Spectra are high-dimensional and collinear, so models depend on careful pre-processing. PLS-DA, SIMCA, support vector machines and random forests were used for the classification of authentic and adulterated samples, while partial least squares regression was used to estimate the adulterant concentration (Menevseoglu, 2022; Malavi et al., 2024). However, the reliability depends on a calibration set that represents the natural variability of the true sample (Moghaddam et al., 2022). Data fusion is the integration of instruments at the raw-data, feature or decision level (Guo et al., 2024). A portable sensor based on high-level fusion could detect 97 % of adulterated EVOO (Weesepoel et al., 2021) and low-level fusion was useful when the sample variability was high (Much et al., 2024).

6. Comparative Performance

Representative results are summarized in Table 1. The accuracy values should be compared with caution because they are from different matrices, adulterants and validation schemes. The application of several techniques (HSI, FTIR, UV-Vis, Raman and GC-MS) to one set of EVOO samples in this order reduced the accuracy (Malavi et al., 2023). Spectroscopic methods can be used for fast screening and chromatographic and DNA-based methods are more specific.

Table 1. Comparative overview of analytical techniques for rapid detection of food adulterants

Technique	Representative result	On-site suitability
NIR and NIR-HSI	93.9-100% accuracy, EVOO (Malavi et al., 2024)	High
Raman and SERS	99% dairy brand accuracy (Feng et al., 2024)	High
FTIR (ATR)	99.8% accuracy, EVOO (Malavi et al., 2023)	Moderate
UV-Vis	99.6% accuracy, EVOO (Malavi et	High

	al., 2023)	
Fluorescence	10% detection limit, coffee (Xie & Tan, 2022)	Moderate
Hyperspectral imaging	100% accuracy, EVOO (Malavi et al., 2023)	Limited
GC-MS, HPLC, LC-MS	93.7% accuracy, EVOO by GC-MS (Malavi et al., 2023)	Low
Benchtop NMR	43 MHz ultrafast 2D NMR (Gouilleux et al., 2018)	Moderate

7. Challenges and Future Perspectives

Calibration models are often instrument-dependent and need updating as varieties and processing change (Moghaddam et al., 2022; McVey et al., 2021). Band overlap limits sensitivity to low-level adulteration, and models built for known adulterants may miss new ones. Harmonized protocols, shared spectral libraries and officially recognized reference methods are still lacking. Miniaturization may extend authentication to small processors, and blockchain traceability will help only if the underlying measurements are reliable (Sreenivasulu, 2025).

Conclusions

Spectroscopic techniques and hyperspectral imaging can detect and often quantify adulterants, while chromatography, mass spectrometry, NMR and DNA-based methods remain necessary for confirmation and origin verification. Standardization, calibration transfer and regulatory acceptance still limit wider use, so portable screening backed by laboratory confirmation is the most practical basis for food authentication.

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Volume: 06 Issue No: 10

GHOST FISHING: A HIDDEN THREAT TO MARINE BIODIVERSITY

Article ID: AG-VO6-I10-54

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Abstract

Marine biodiversity is increasingly threatened by human activities that extend beyond the immediate exploitation of ocean resources. Among these threats, ghost fishing represents a persistent but often overlooked source of marine wildlife mortality. It occurs when lost, abandoned or discarded fishing gear continues to capture or entangle aquatic organisms without human intervention. In addition to affecting fish, crustaceans, sea turtles, seabirds and marine mammals, abandoned fishing gear can damage sensitive habitats and contribute to long-term marine pollution. Its ecological consequences are particularly concerning where vulnerable species and already stressed ecosystems are involved. Evidence from Indian waters, including documented wildlife interactions and experimental observations of continued capture by lost fishing nets, highlights the relevance of this issue to marine conservation. This article examines ghost fishing as a threat to marine biodiversity, explores its ecological and socioeconomic implications, and evaluates strategies for prevention and management. It argues that responsible gear management, effective recovery programmes, scientific monitoring and collaboration with fishing communities are essential to reducing the persistent ecological risks posed by abandoned fishing equipment.

Keywords: Ghost fishing, marine biodiversity, abandoned fishing gear, wildlife conservation, marine pollution, sustainable fisheries.

Introduction

The ocean supports an extraordinary diversity of life, from microscopic plankton to the largest marine mammals. These organisms form interconnected ecological networks that sustain food webs, regulate ecosystem processes and support human livelihoods. Yet, the pressures affecting marine biodiversity are not limited to the activities that take place directly under human supervision. Some continue long after the activity responsible for them has ceased.Among the less visible of these pressures is ghost fishing, a phenomenon in which lost, abandoned or discarded fishing gear continues to capture and entangle marine organisms. Without a fisher present to retrieve the catch or release non-target animals, the equipment becomes an uncontrolled source of mortality.

Ghost fishing is particularly concerning because it combines direct harm to wildlife with the persistence of fishing materials in marine environments. Its victims may never be recorded, and the resulting damage can remain hidden beneath the surface. Although not every lost net continues catching organisms for the same length of time, abandoned fishing gear can remain hazardous under suitable environmental conditions.

Understanding ghost fishing as a biodiversity issue requires looking beyond individual entanglement incidents. It involves examining the species affected, the habitats exposed to damage, the persistence of synthetic materials and the management practices that determine whether lost equipment becomes a continuing ecological threat.

The Persistence of Fishing Gear

Modern fishing equipment is designed for strength, durability and efficient capture. Gillnets, traps, hooks and lines enable fisheries to harvest aquatic resources, but these same characteristics can make lost gear dangerous to marine life.Equipment may be lost during storms, strong currents or accidental entanglement with underwater structures. Gear conflicts, operational difficulties and damage during fishing activities can also contribute. In some circumstances, retrieval is too expensive or dangerous, while inadequate collection facilities make the responsible disposal of damaged equipment difficult.

The term *abandoned, lost or otherwise discarded fishing gear* (ALDFG) describes this broader problem. However, its ecological effects depend on the type of equipment and the conditions in which it is lost. Gillnets may continue to capture organisms when their mesh remains functional, while abandoned traps can retain their capture potential under certain

conditions. Ropes and fishing lines may remain entanglement hazards even when they no longer function effectively as fishing equipment.The Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programme (UNEP) have identified ghost fishing among the important consequences of abandoned fishing gear, alongside habitat damage, navigation hazards and economic losses.

Biodiversity Under Pressure

The most immediate ecological consequence of ghost fishing is the injury and mortality of marine organisms. Fish can become trapped in netting, crustaceans may remain inside abandoned traps, and turtles, seabirds and marine mammals can become entangled in discarded lines and ropes. Depending on the circumstances, these encounters may cause physical injuries, restrict movement, interfere with feeding or result in death.For marine animals that must surface to breathe, underwater entanglement can be especially dangerous. Even when an animal survives, restricted movement or injury may reduce its ability to feed, migrate or avoid predators. The consequences therefore extend beyond immediate mortality.

A scientific review by Stelfox, Hudgins and Sweet examined ghost-gear entanglement involving marine mammals, reptiles, sharks and rays, demonstrating the breadth of wildlife groups exposed to abandoned fishing equipment. Nevertheless, the frequency of such incidents and their population-level consequences remain difficult to quantify in many regions.

This distinction is important in biodiversity assessment. Documenting the death or entanglement of individual animals establishes that a hazard exists, but determining whether it affects an entire population requires additional information about population size, reproductive rates, background mortality and exposure frequency. The lack of comprehensive data should not be interpreted as evidence that the threat is insignificant; rather, it highlights the need for better monitoring.

The ecological significance of ghost fishing also extends to species interactions. Marine organisms contribute to food-web relationships, nutrient cycling and the regulation of other populations. Unnecessary mortality across different groups of organisms may place additional pressure on these interconnected systems. The extent to which ghost fishing changes community composition or food-web structure, however, varies among ecosystems and requires further investigation.

India's Waters: Evidence of a Hidden Threat

India's extensive coastline supports diverse marine ecosystems and fishing communities, making the management of abandoned fishing gear an important conservation concern. Research from Indian waters provides evidence that ghost fishing affects wildlife and that lost fishing equipment can retain its ability to capture aquatic organisms.

A study published in *Biological Conservation* in 2024 examined reported interactions between abandoned fishing gear and wildlife in India. The researchers documented 35 affected animal species, including 13 species classified as threatened. Sea turtles and marine mammals were among the groups frequently represented in the reported incidents.

These observations highlight the potential conservation significance of ghost fishing. However, because the study relied on publicly available reports, including social media observations, the findings cannot be considered a complete estimate of wildlife affected throughout India. Incidents that are never photographed or reported may remain undocumented, illustrating a broader challenge in assessing threats that occur beneath the water.

Experimental evidence from Vembanad Lake in Kerala provides a complementary perspective. In a study published in 2023, Thomas and colleagues investigated the continued capture capacity of simulated lost shrimp gillnets at Aroor. Across two seasonal experiments, the researchers recorded 251 specimens belonging to 27 species. Capture efficiency declined over time, but the nets continued catching organisms until approximately day 15 in one experiment and day 50 in the other.



Figure 1 Fish trapped in ghost net

The researchers observed that particulate matter and detritus accumulated on the nets, making them more visible and reducing their capture efficiency. The findings demonstrate that

the functional life of lost fishing gear depends partly on environmental conditions. A reduction in capture efficiency does not necessarily mean that the ecological hazard disappears immediately.

Another study by Daniel and Thomas, published in *Marine Policy* in 2023, examined fishing-related debris and disposal practices along the Kerala coast. By combining interviews with fishers and beach-litter assessments, the researchers highlighted the importance of accessible collection facilities and improved management of unwanted fishing equipment.

Taken together, these studies illustrate two connected dimensions of the problem: abandoned gear can continue affecting aquatic organisms, while inadequate disposal systems can increase the likelihood that unwanted fishing materials enter the environment. However, findings from individual locations cannot represent all Indian fisheries. Broader monitoring across different coastal regions and fishing practices is needed to identify areas of greatest concern and guide targeted conservation measures.

Beyond Entanglement: Habitat Damage and Pollution



Figure 2 Sea turtle trapped in ghost net

Ghost fishing is closely connected to, but distinct from, the wider problem of marine plastic pollution. Many fishing nets and ropes are manufactured from synthetic polymers that resist degradation. Although this durability makes them useful in fishing operations, it also allows lost equipment to persist after its intended use has ended.

As abandoned gear moves with currents, it may become entangled around coral reefs, rocky seabeds and other underwater structures. Depending on its location and movement, the equipment may cover marine organisms, disturb sensitive habitats or interfere with areas used for shelter and feeding. Such damage can be particularly concerning in ecosystems already affected by other human pressures. Over time, physical damage and environmental processes may also fragment synthetic materials into smaller particles.

Ghost fishing therefore represents more than a temporary entanglement hazard. It links the direct mortality of marine organisms with the long-term persistence of discarded materials.

Effective conservation measures must address both dimensions through safe gear recovery, improved disposal practices and the prevention of equipment loss.

The Human Dimension of Ghost Fishing

The consequences of abandoned fishing gear are not confined to wildlife. Fishing equipment represents a substantial investment for many fishers, and its loss can create financial difficulties. Replacing nets, lines and traps may be expensive, while recovery operations require additional labour, fuel and equipment. Ghost fishing also wastes fishery resources. Organisms caught by abandoned gear may die without contributing to a usable harvest, while lost equipment can become entangled with active gear or create hazards for vessels. These impacts may be particularly challenging for small-scale fishing communities with limited resources.

Importantly, ghost fishing should not be attributed solely to irresponsible behaviour. Severe weather, accidental gear loss, operational constraints and inadequate waste-management infrastructure can all contribute. Measures that focus exclusively on individual responsibility may therefore fail to address the underlying causes.

Reducing gear loss can lower replacement costs while also reducing avoidable wildlife mortality and marine pollution.

From Prevention to Recovery

The most effective response to ghost fishing begins before fishing equipment is lost. Regular maintenance, safer handling practices and improved operational procedures can reduce accidental loss. When gear does disappear, prompt reporting and identifiable equipment can improve the prospects of recovery.

The FAO's *Voluntary Guidelines on the Marking of Fishing Gear* provide an international framework for responsible gear management. Marking can help establish ownership and support reporting and retrieval, while accessible collection facilities at fishing harbours and landing centres provide practical alternatives to discarding damaged equipment.

Recovery programmes can remove abandoned nets and other gear from affected waters, but retrieval must be undertaken carefully. Equipment entangled around sensitive habitats may require specialist assessment to prevent further damage during removal. Recovery should therefore be guided by ecological considerations rather than the quantity of material removed alone.

Technological innovation may also contribute. Researchers are investigating alternative materials and modified gear designs that could reduce the persistence or capture potential of lost equipment. Biodegradable materials and modified traps may offer benefits under appropriate conditions, but their effectiveness depends on durability, environmental conditions and performance during normal fishing operations. They should be evaluated carefully rather than regarded as universal solutions.

Their knowledge of local waters, seasonal conditions and common gear-loss locations can help identify areas requiring intervention. Cooperation among fishers, scientists, fisheries departments, harbour authorities and conservation organisations can strengthen reporting systems, improve disposal practices and assess the effectiveness of management programmes.Better estimates of gear loss, the duration of capture potential, the species affected and the outcomes of recovery efforts would allow conservation resources to be directed towards the most significant risks. In India, geographically broader studies are particularly important for developing management strategies suited to different coastal ecosystems and fishing practices.

Conclusion

Ghost fishing represents a hidden but persistent threat to marine biodiversity. Lost, abandoned and discarded fishing gear can kill marine organisms, expose vulnerable species to additional mortality, disturb ecological relationships, damage sensitive habitats and contribute to long-term marine pollution. Although the extent of its population-level consequences remains uncertain in many regions, the documented effects demonstrate that abandoned fishing equipment can continue to impose avoidable risks on marine ecosystems.

Evidence from India reinforces the need for stronger monitoring and locally appropriate management measures. Addressing the problem requires more than removing abandoned nets after damage has occurred. It demands a preventive approach that combines responsible fishing practices, accessible disposal facilities, safe recovery operations, scientific research and meaningful participation by fishing communities. Marine biodiversity depends on the continued functioning of complex ecological relationships. Protecting it requires attention not only to the resources extracted from the ocean but also to the equipment and waste left behind. Preventing ghost fishing is an essential step towards reducing avoidable harm and supporting healthier, more resilient marine ecosystems.

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Volume: 06 Issue No: 10

MANGROVES AS CLIMATE WARRIORS: COASTAL PROTECTION AND CARBON STORAGE

Article ID: AG-VO6-I10-55

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Abstract

Mangrove forests, once dismissed as coastal wasteland, are increasingly recognized as one of the most effective nature-based solutions to climate change. This article examines their dual role as "climate warriors" physically shielding coastlines from storm surges and erosion through dense root networks, while storing carbon in waterlogged soils at rates far exceeding tropical rainforests. Drawing on case studies from the Sundarbans, Tamil Nadu's Pichavaram wetlands, Vietnam's restoration programmes and Muthupet mangrove rehabilitation,the article traces how these ecosystems also sustain coastal fisheries as nurseries for marine life, even as they face mounting threats from aquaculture expansion, coastal development, and pollution. It concludes by outlining the restoration and policy efforts from national missions to blue carbon markets now working to protect and expand mangrove cover, positioning their conservation as urgent climate infrastructure rather than a peripheral environmental concern.

Keywords: Mangroves, Blue carbon, Coastal protection, Climate change mitigation, Carbon sequestration.

Introduction

Climate change is increasing the frequency and severity of coastal hazards such as storm surges, cyclones, and sea-level rise, placing growing pressure on shorelines and the communities that depend on them. Among the ecosystems offering natural resilience against these threats,

mangrove forests have drawn particular attention for their dual contribution to climate mitigation and adaptation. Mangroves are salt-tolerant trees occupying intertidal zones across tropical and subtropical coasts, where their root systems reduce wave energy and stabilize shorelines, while their waterlogged soils store carbon at rates that can exceed those of tropical rainforests.

This dual function has been documented by international conservation organizations. WWF has reported that mangroves can store several times more carbon than other tropical forest types, while the UNDP has described mangroves as "climate warriors" for their combined role in coastal protection and climate change mitigation — a framing that countries including Vietnam and India have incorporated into national conservation and restoration programmes.

This article examines the two primary functions of mangrove ecosystems — coastal protection and carbon storage — and reviews restoration efforts in the Sundarbans, Pichavaram, and Vietnam to assess how this research has translated into measurable outcomes.

What makes mangroves unique?

Mangroves are among the few tree species adapted to survive in saline, oxygen-poor intertidal zones. Two mechanisms allow this: salt tolerance and aerial root adaptations. Some species exclude salt at the root level through ultrafiltration, while others absorb and later excrete it through specialized leaf glands. To cope with waterlogged, low-oxygen soil, many mangroves develop pneumatophores — vertical breathing roots that extend above the mud — while others rely on stilt-like prop roots for both structural support and aeration. More than 60 mangrove species exist globally, each adapted to specific salinity ranges and tidal conditions, which accounts for structural differences between mangrove stands in different regions. These combined adaptations allow mangroves to occupy a coastal niche that few other plant species can tolerate.



Figure 1. Pneumatophores in mangroves

The coastal shield mechanism

The dense root networks of mangroves — prop roots and pneumatophores — act as a physical barrier against wave energy. As storm surges and wind-driven waves pass through this root structure, friction and turbulence dissipate much of their force before reaching the shoreline. Research has recorded wave height reductions of roughly 13–66% within the first 100 metres of mangrove forest, with the greatest attenuation occurring near the forest edge. The same root systems trap and stabilize sediment, allowing coastlines to accumulate soil over time rather than erode. During cyclones and tsunamis, this combination of wave attenuation and sediment stabilization reduces the height and force of water reaching inland areas, lowering damage to settlements, farmland, and aquaculture infrastructure. Functionally, a healthy mangrove belt operates as a self-maintaining coastal barrier, in contrast to engineered structures like seawalls, which degrade over time and require ongoing maintenance.

Blue carbon storage

Mangroves are classified as "blue carbon" ecosystems because most of the carbon they capture is stored not in above-ground biomass, but in the waterlogged soil beneath them. Organic matter — fallen leaves, roots, and debris — accumulates in this oxygen-poor sediment, where decomposition slows significantly, allowing carbon to remain sequestered for extended periods rather than being released back into the atmosphere. By some estimates, this allows mangrove ecosystems to store up to four times more carbon than tropical rainforests. This also means mangrove carbon storage is reversible: when a mangrove forest is cleared or drained, the sediment is exposed to oxygen, and the stored carbon can be released as emissions. This makes conservation of existing mangrove forests, rather than reliance on new planting alone, a priority from a carbon-management perspective.

Nursery for marine life

Mangrove root systems provide shelter for juvenile marine species during their most vulnerable life stages. The structural complexity of submerged roots creates refuge from predators for young fish, shrimp, and crabs, which rely on this habitat before migrating to seagrass beds, coral reefs, or open water. Species such as groupers and several commercially important shrimp varieties use mangroves as nursery grounds during early development. This function has direct economic relevance: coastal and offshore fisheries in mangrove-adjacent regions have been associated with higher catch volumes, reflecting the ecological dependency of

several commercial species on mangrove habitats. For coastal communities relying on fishing and small-scale aquaculture, mangrove ecosystems function as a biological foundation for sustained fishery productivity.

Threats and decline

Mangroves are declining faster than many other forest types, and about 35% of the world's original mangrove cover has already been lost. Conversion to aquaculture is the leading driver, particularly shrimp farming in Southeast Asia, and it is also a major pressure in Indian states such as Andhra Pradesh, West Bengal, and Gujarat. Other causes include timber extraction, fuelwood and charcoal production, disease, and storm damage. In a satellite study covering 1996-2010, 38% of the mangrove areas assessed were affected by human activity. These losses also carry a climate cost, since clearing exposes buried sediment carbon to oxygen and converts a carbon sink into a source of emissions.

Case study

Four sites show how mangrove conservation plays out in practice.

Vietnam: Since 2017, UNDP has worked with the Ministry of Agriculture and Rural Development and five provinces to plant and rehabilitate over 4,000 ha of mangroves. A Canada-funded project will add another 600 ha. Carbon stock assessments across 28 coastal provinces are building a national mangrove database, which supports Vietnam's climate commitments and carbon-market planning. National policy backs this through the 2021 scheme for protecting and developing coastal forests (2021-2030).

Sundarbans (India and Bangladesh): The Sundarbans cover about 10,000 km² and form the world's largest area of mangrove forest. They are the only mangrove habitat inhabited by the Bengal tiger. India's portion and Bangladesh's portion are listed separately as UNESCO World Heritage Sites. The forest serves as a nursery for marine organisms and a buffer against cyclones and sea-level rise. It is also under pressure from rising salinity and reduced freshwater flow from upstream projects, and the IUCN's 2025 assessment rates its conservation outlook as "significant concern".

Pichavaram (Tamil Nadu): Pichavaram was designated a Ramsar site in 2022 and covers about 1,479 ha. It supports over 1,000 families through fishing, firewood collection, non-timber forest products, and grazing. It has been a Reserve Forest since 1893, yet the Ramsar record notes it has no management plan. Remote sensing showed that about 54% of its forest was degraded in 1986.

Joint restoration by the Tamil Nadu Forest Department, the M.S. Swaminathan Research Foundation (MSSRF), and local communities raised forest cover by about 60 ha by 1996. MSSRF also set up a mangrove gene bank at the site and reported survival rates of up to 70% in degraded areas. During the 2004 tsunami, the dense mangroves around Chidambaram reportedly absorbed and dissipated wave force, which raised local support for restoration.

Muthupet (Tamil Nadu): Muthupet, in Thiruvarur district at the southern end of the Cauvery delta, is the largest mangrove forest in Tamil Nadu, covering about 120 km² and dominated by *Avicennia marina*. It lies within the Point Calimere Ramsar site. Siltation, blocked tidal flow, and hypersalinity degraded about 60% of its 11,886 ha, and Cyclone Gaja (2018) caused further damage, although the mangroves reportedly reduced wind force and protected Muthupet town. Restoration includes over 2,000 ha regenerated under a World Bank-supported tsunami reconstruction project, and 2,057 ha added under the Green Tamil Nadu Mission (2022-25) through planting and canal desilting. Muthupet is also the only place in India where traditional canal fishing is practised, which links local fishing livelihoods to mangrove health.



Figure 2. Mangrove forest in Sundarbans.



Figure 3.Mangrove forest in Pichavaram

Conclusion

Mangroves provide coastal protection, carbon storage, and fishery support within a single ecosystem. Their root networks reduce wave energy and stabilise shorelines, their waterlogged soils store carbon at rates that can exceed those of tropical rainforests, and their roots shelter juvenile fish and shrimp that support coastal livelihoods. These benefits are at risk, as about 35% of the world's original mangrove cover has been lost, mainly to aquaculture conversion. Because clearing releases stored sediment carbon, protecting existing forests is as important as planting new ones. The Pichavaram,Muthupet and Vietnam cases show that community-based and government-backed restoration can recover cover, while the Sundarbans shows that even the largest mangrove forests remain vulnerable to salinity and altered freshwater flow. Mangrove

conservation therefore needs to be treated as part of coastal and climate planning, supported by monitoring, carbon assessment, and long-term management.

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Volume: 06 Issue No: 10

EL NINO AND KHARIF PULSES: A CLIMATE CHALLENGE FOR INDIA'S PULSE FARMERS

Article ID: AG-VO6-I10-56

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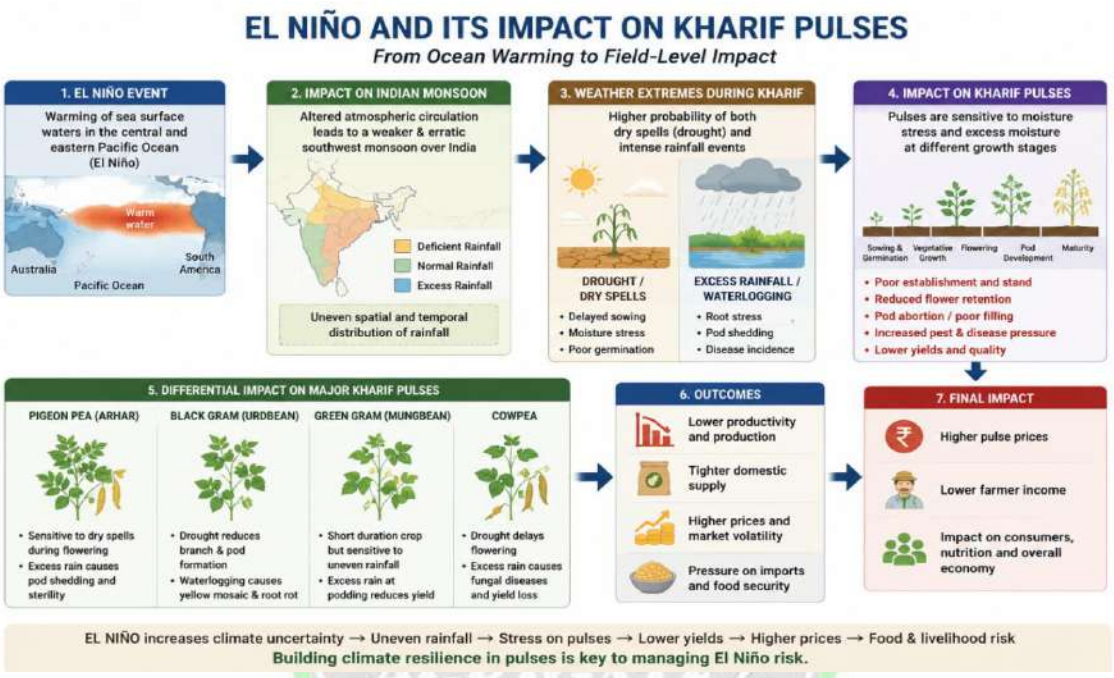
Introduction

Every year, India's Kharif season begins with a simple hope: timely monsoon rains, healthy crops, and a good harvest. For pulse farmers, however, weather conditions can sometimes become an unpredictable partner. India's Kharif crop prospects remain challenging midway through the southwest monsoon, with cultivation of Kharif crops in general—rice, coarse cereals, oilseeds, and cotton—and pulses in particular facing an uncertain outlook. Although heavy rainfall in July reduced the risk of drought, rainfall has remained uneven, with key pulse-producing states such as Maharashtra, Karnataka, and Andhra Pradesh recording significant deficiencies.

Pulses acreage is also lagging behind the previous year. As of July 24, 2026, pulses had been planted on 8.5 million hectares, compared with 9.1 million hectares during the corresponding period in 2025. The final Kharif pulse acreage in 2025 was 11.9 million hectares, compared with a normal five-year average of 12.4 million hectares. Thus, the area planted by July 24, 2026, was 0.6 million hectares lower than during the corresponding period in 2025 and 3.9 million hectares below the five-year average. Since the planting window had effectively closed by mid-July, the final acreage for 2026 is unlikely to reach the 2025 level, let alone the five-year average.

The Government of India has set a Kharif 2026–27 pulses production target of 8.4 million tonnes. However, production could fall short of this target if August rainfall remains inadequate or uneven. A clearer assessment of the crop situation is expected by the end of August. To ensure domestic availability, the government has allowed liberal imports of pulses until March 2027. With the festival season approaching, demand for pulses is expected to

increase, although weak rural income growth and inflationary pressures could moderate consumption. One of the major climate phenomena capable of disturbing this delicate balance is El Nino. El Nino refers to the periodic warming of surface waters in the central and eastern Pacific Ocean. Although this phenomenon occurs thousands of kilometres away from India, it



can influence global atmospheric circulation and weather patterns, including the Indian monsoon. Consequently, variations in rainfall and temperature associated with El Niño can have important implications for Kharif pulse production (https://saskpulse.com/ resources/indian-kharif-pulse-crops-face-monsoon-uncertainty).

Kharif pulses such as pigeonpea (arhar), blackgram (urdbean), greengram (mungbean), and cowpea are particularly dependent on favourable monsoon conditions during critical stages of crop establishment and development. Changes in the timing, distribution, and intensity of rainfall, together with temperature fluctuations, can influence germination, vegetative growth, flowering, pod development, and ultimately grain yield. Understanding the potential relationship between El Nino-driven climate variability and pulse productivity is therefore important for developing suitable climate-resilient production strategies.

El Nino and Its Implications for Kharif Pulses

Kharif pulses are largely dependent on rainfall. Unlike many irrigated crops, a large proportion of pulse cultivation is carried out under rainfed conditions. This makes pulses

particularly sensitive to an uneven monsoon. During an El Nino year, the Indian monsoon may be weaker than normal, although the effect is not identical in every El Nino year or in every part of India. The bigger concern for farmers is not simply the total amount of rainfall, ***but when, where and how the rain arrives.*** A delayed monsoon can postpone sowing. A long dry spell after sowing can reduce germination and weaken young plants. On the other hand, intense rainfalls over a short period can cause waterlogging, soil erosion and nutrient loss (Yadav et al., 2022; NITI Aayog, 2025).

Pigeonpea: Between Dry Spells and Heavy Rains

Pigeon pea is one of the India's most important kharif pulses. It is relatively drought tolerant compared with some other crops, but prolonged moisture stress during critical stages can still reduce plant growth, flowering and pod formation.If El Nino results in a delayed or poorly distributed monsoon, farmers may face difficulties in establishing the crop. Moisture stress during flowering and pod development can be particularly damaging.At the same time, excessive rainfall is not necessarily good news. Waterlogging can damage roots and create favourable conditions for diseases. Thus, pigeon pea requires not just rain, but well-distributed rain and good drainage (Murali et al., 2025; Mushoriwa et al., 2024)

Mung and Urd: Short-duration crops

Green gram and black gram are generally short-duration crops. Their relatively short growing period can be an advantage when the monsoon behaves normally. But it can also become a weakness when rainfall is delayed or interrupted. A late start to the monsoon may force farmers to postpone sowing. If a prolonged dry spell follows, the crop may suffer at the seedling or vegetative stage. High temperatures combined with moisture stress can further affect flowering and pod development. For these crops, timely sowing, moisture conservation and the use of suitable short-duration or climate-resilient varieties can help reduce weather-related risks (Van Haeften et al., 2023; Agronomy, 2021).

The hidden effect: Pests and diseases

El Nino does not affect pulses only through rainfall. Changes in temperature and humidity can also influence the occurrence and spread of pests and diseases. A stressed crop may become more vulnerable to pest attack. Weather conditions can also alter the life cycle and insect's population In pigeon pea, for example, pod borers are a major concern. Farmers

therefore need to monitor fields regularly rather than waiting until visible damage becomes severe (Singh et al., 2023; Srivastava & Joshi, 2011)

How Weather Could Influence Pulse Prices?

The impact of El Nino can move beyond the farm. If adverse weather reduces domestic pulse production, market arrivals may decline. Lower supply can put upward pressure on prices, affecting both farmers and consumers. For farmers, higher prices may provide some compensation for lower yields. But this benefit is not guaranteed: production costs, local market conditions, storage capacity and the timing of sales all influence farm income. For consumers, reduced domestic production can increase dependence on imports. This is particularly important for India because pulses are a major source of affordable protein for millions of households (NITI Aayog, 2025; Damodaran, 2026).

Transforming Climate Challenges into Opportunities

El Nino cannot be prevented, but its impact can be managed. The first line of defence is better weather-based farm planning. Farmers can reduce risk by selecting varieties suited to the local growing period, adjusting sowing dates according to monsoon conditions, conserving soil moisture and maintaining proper drainage. Crop diversification and suitable intercropping systems can also spread risk. Access to timely weather forecasts is becoming increasingly important. Instead of following a fixed calendar every year, farmers can use seasonal forecasts and short-term weather information to make decisions about sowing, irrigation, fertilizer application and pest management. Agricultural extension services also have an important role. When abnormal monsoon conditions are forecast, farmers need practical advice not just warnings. Information should reach villages quickly and in local languages.

Broader Lessons for Climate-Resilient Pulse Production

El Nino reminds us that agriculture is closely connected to climate, even when the climatic disturbance begins far away. For kharif pulses, the challenge is especially significant because millions of farmers depend on the monsoon. But the story need not be one of loss. Pulses themselves are valuable crops for a changing climate because many require less water than several major irrigated crops and can fit well into diversified farming systems. The future of kharif pulses will therefore depend on a combination of climate-resilient varieties, efficient water management, timely weather information, better crop insurance, improved extension services and informed farmer decisions.

El Nino may bring uncertainty, but preparedness can reduce that uncertainty. For India's pulse farmers, the goal should not simply be to wait for a favourable monsoon—it should be to build a farming system capable of coping with an increasingly unpredictable one.

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Volume: 06 Issue No: 10

PESTS OF MUSHROOM AND THEIR MANAGEMENT

Article ID: AG-VO6-I10-57

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Introduction

Mushroom cultivation has emerged as one of the most promising agro-based enterprises owing to the increasing consumer demand for nutritious and functional foods. Mushrooms are rich sources of proteins, vitamins, minerals, dietary fibre and bioactive compounds, and their cultivation offers an efficient means of converting agricultural wastes into valuable food products. In India, the cultivation of button mushroom (*Agaricus bisporus*) and oyster mushroom (*Pleurotus* spp.) has expanded considerably because of their high market demand and relatively simple production technologies. However, the successful production of mushrooms is often constrained by the incidence of several insect and arthropod pests that adversely affect both yield and quality. The warm temperatures, high humidity and abundance of organic matter maintained within mushroom growing houses create ideal conditions for the multiplication of these pests. They may directly damage mushroom mycelium and fruiting bodies or indirectly reduce productivity by transmitting disease-causing organisms. Therefore, understanding the biology, damage symptoms and management practices of important mushroom pests is essential for profitable and sustainable mushroom cultivation.

2. Major Pests of Mushroom

The major pests associated with mushroom cultivation are presented in Table 1.

Table 1. Major pests associated with mushroom cultivation

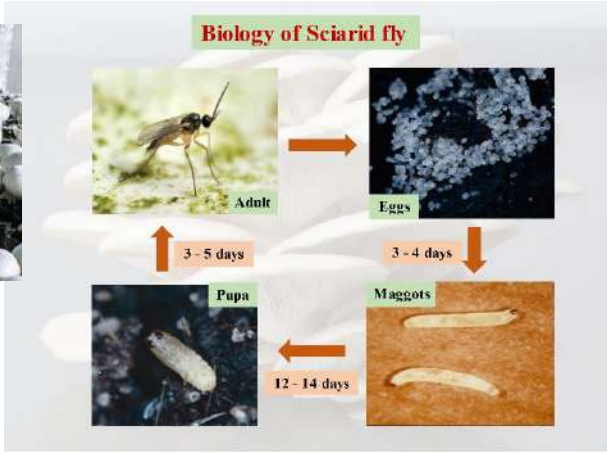
Pest group	Examples	Major stage causing damage	Nature of damage
Sciarid flies (Sciaridae)	*Lycoriella ingenua*, *Bradysia* spp.	Larvae	Feeding on mycelium, pinheads and fruit bodies

Phorid flies (Phoridae)	*Megaselia halterata*	Larvae	Damage to mycelium and disruption of spawn run
Springtails (Collembola)	*Lepidocyrtus* spp., *Seira* spp.	Nymphs and adults	Feeding on fungal hyphae and developing mushrooms
Mites (Acari)	*Tyrophagus putrescentiae, Tarsonemus myceliophagus*	Nymphs and adults	Damage to mycelium and fruiting bodies
Nematodes	*Aphelenchoides* spp., *Ditylenchus* spp.	Juveniles and adults	Destruction of fungal hyphae and poor spawn growth

3. Sciarid Flies (Fungus Gnats)

- **Scientific classification:** Order Diptera; family Sciaridae.
- **Important species:** *Lycoriella ingenua*, *Lycoriella castanescens* and *Bradysia* spp.
- **Identification:**
  - Adults are small, dark-coloured, mosquito-like flies measuring approximately 3–5 mm.
  - Larvae are translucent or whitish, with characteristic shiny black head capsules.
- **Biology:**
  - Females lay eggs in moist compost, casing materials or organic substrates.
  - Eggs hatch into larvae, which feed on fungal mycelium and developing mushrooms.
  - Pupation occurs in the substrate, followed by adult emergence.
- **Nature of damage:**
  - Larvae feed on mycelium, primordia and developing fruit bodies.
  - Feeding produces tunnels and irregular lesions in mushroom tissues.
  - Infestation results in poor pinhead formation, malformed mushrooms and reduced yield.
  - Adult flies may contribute to the dispersal of mites, nematodes and disease-causing organisms.
- **Management:**
  - Pasteurize compost and casing materials using validated temperature–time combinations.



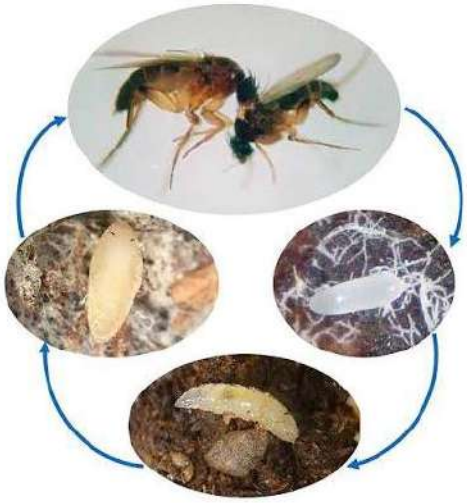


- Install insect-proof screens and double-door entry systems.
- Use yellow sticky traps to monitor adult populations.
- Remove spent compost and crop debris promptly.
- Apply the entomopathogenic nematode *Steinernema feltiae* where effective and locally recommended.
- Use insecticides only when registered for the crop and permitted under applicable regulations.

4. Phorid Flies

- **Scientific classification:** Order Diptera; family Phoridae.
- **Important species:** *Megaselia halterata*.
- **Identification:**
  - Adults are small flies with a characteristic hump-backed appearance.
  - They exhibit rapid, erratic running and flying movements.
- **Biology:**
  - Eggs are deposited in suitable compost or substrate environments.
  - Larvae develop in association with mushroom mycelium.
  - Development and population growth are favoured by suitable temperature, moisture and food availability.
- **Nature of damage:**
  - Larvae feed on mushroom mycelium and interfere with normal substrate colonization.
  - Infestation may result in patchy spawn run, delayed cropping and uneven mushroom production.
  - Adult flies may facilitate the spread of pathogens between growing areas.

- **Management:**
  - Prevent adult entry through insect-proof screening.
  - Maintain sanitation in compost preparation, spawning and cropping areas.
  - Avoid overlapping crop cycles where they facilitate pest carry-over.
  - Monitor adult populations using sticky traps and routine inspections.
  - Use approved control measures only when monitoring indicates a need.





5. Springtails

- **Scientific classification:** Class Entognatha; order Collembola.
- **Important examples:** *Lepidocyrtus* spp. and *Seira* spp.
- **Identification:**
  - Minute, wingless arthropods found in moist substrates.
  - Many species possess a forked jumping organ called the furcula.
- **Biology:**
  - Eggs are deposited in moist organic material.
  - Immature stages resemble adults and develop through successive moults.
  - Populations increase under favourable moisture and substrate conditions.
- **Nature of damage:**
  - Some species feed on fungal hyphae, mycelium and developing fruit bodies.
  - Heavy infestations may interfere with mushroom development.
  - Their presence on harvested mushrooms can reduce market quality.

- **Management:**
    - Maintain appropriate moisture levels and avoid waterlogging.
    - Ensure proper substrate preparation and pasteurization.
    - Improve ventilation without compromising the humidity required for mushroom growth.
    - Clean growing rooms and remove crop residues.
    - Monitor populations, particularly in persistently wet areas.

6. Mites

- Scientific classification: Class Arachnida; subclass Acari.
- Important examples: *Tyrophagus putrescentiae*, *Tarsonemus myceliophagus* and *Pygmephorus* spp.
- **Identification:**
    - Mites are minute, soft-bodied arthropods that are often difficult to detect without magnification.
    - They may occur in compost, casing materials, mushroom debris and growing structures.
- **Biology:**
    - Eggs develop into immature stages and adults.
    - Rapid population increase may occur when moisture, temperature and food availability are favourable.
- **Nature of damage:**
    - Mycophagous mites feed on fungal tissues and may damage developing mushrooms.
    - Infestation can result in surface injury, impaired mycelial growth and reduced productivity.
    - Some species may carry fungal spores or other microorganisms.
- **Management:**
    - Use properly prepared compost and clean casing materials.
    - Clean and disinfect growing rooms, tools and equipment between production cycles.
    - Remove spent substrates and infested materials.

- Inspect substrates and mushrooms regularly for early detection.
- Use acaricides only when specifically approved for the intended application.

7. Nematodes

- **Scientific classification:** Phylum Nematoda.
- **Important examples:** Aphelenchoides spp. and Ditylenchus spp.
- **Identification:**
  - Nematodes are microscopic, elongated, worm-like organisms.
  - Mycophagous species are associated with fungal mycelium and organic substrates.
- **Biology:**
  - Eggs hatch into juveniles, which develop into adults through successive moults.
  - They may be introduced through contaminated compost, casing materials, water or equipment.
- **Nature of damage:**
  - Feeding damages fungal hyphae and interferes with mycelial development.
  - Infestation causes patchy spawn run, delayed pinhead formation and reduced yields.
  - Severe infestation can lead to substantial crop loss.
- **Management:**
  - Use properly pasteurized substrates and clean casing materials.
  - Maintain strict sanitation during spawning and cropping.
  - Prevent cross-contamination through contaminated tools, water and crop residues.
  - Use validated substrate heat-treatment procedures before spawning.
  - Seek laboratory confirmation when nematode infestation is suspected.

8. Comparative Features of Major Mushroom Pests

Table 2. Comparison of pest biology, damage and management

Pest	Principal feeding site	Major symptom	Important management measure
Sciarid flies	Mycelium, primordia and fruit bodies	Tunnels, damaged pinheads and	Exclusion, sanitation and biological control

		malformed mushrooms	
Phorid flies	Primarily mycelium	Patchy spawn run and delayed cropping	Insect-proof screening and sanitation
Springtails	Fungal hyphae and developing mushrooms in susceptible species	Feeding injury and reduced quality	Moisture management and hygiene
Mites	Mycelium and fungal tissues, depending on species	Impaired growth and surface injury	Clean substrates and equipment sanitation
Nematodes	Fungal hyphae	Poor spawn run and reduced yield	Substrate pasteurization and prevention of contamination

9. Integrated Pest Management (IPM) in Mushroom Cultivation

Integrated pest management combines preventive, physical, biological and, where necessary, chemical methods to reduce pest damage while maintaining mushroom quality and food safety.

9.1 Preventive and cultural methods

- Use quality spawn from reliable sources.
- Prepare compost and casing materials using validated pasteurization procedures.
- Maintain cleanliness in growing rooms, corridors and substrate preparation areas.
- Remove spent compost, diseased mushrooms and crop debris promptly.
- Clean and disinfect equipment between production cycles.
- Prevent pest carry-over between successive crops.

9.2 Physical and mechanical methods

- Install insect-proof screens on ventilation openings.
- Use double-door entry systems and maintain door discipline.
- Place yellow sticky traps at suitable locations for monitoring flying insects.
- Inspect compost, casing materials and mushroom beds regularly.
- Remove heavily infested material using appropriate sanitation procedures.

9.3 Biological control

- Entomopathogenic nematodes: *Steinernema feltiae* can suppress susceptible sciarid fly larvae when applied under suitable conditions.
- Predatory mites: *Stratiolaelaps scimitus* may help regulate susceptible fungus gnat larvae and other small arthropods.
- Biological compatibility: Select agents according to the target pest, mushroom production stage and environmental conditions.
- Application: Follow validated recommendations for application rate, timing, moisture and compatibility with other management measures.

9.4 Chemical control

- Chemical pesticides should be considered only when preventive and other suitable measures are insufficient.
- Verify that the product is legally registered or specifically permitted for the intended use in mushroom cultivation.
- Follow the label for dose, application method, timing and worker protection.
- Observe all applicable pre-harvest intervals and residue requirements.
- Avoid indiscriminate spraying, which can lead to pesticide residues, resistance development and adverse effects on beneficial organisms.

9.5 Monitoring and decision-making

Table 3. IPM schedule for mushroom pest management

Production stage	Recommended action	Purpose
Before compost preparation	Clean and sanitize the production area	Reduce carry-over of pests
Compost preparation	Apply validated pasteurization and conditioning procedures	Eliminate susceptible pest stages
Spawning	Use clean spawn, tools and handling practices	Prevent pest introduction
Casing	Use clean casing material and inspect for infestation	Reduce the risk of establishment
Crop development	Inspect beds and use sticky traps	Detect early pest activity

Harvesting	Remove damaged mushrooms and crop residues	Reduce pest persistence
After cropping	Remove spent compost and clean the growing room	Break the pest life cycle

Conclusion

The successful cultivation of button and oyster mushrooms depends largely on effective management of the diverse pests associated with these production systems. Sciarid flies, phorid flies, springtails, mites and nematodes are capable of causing serious economic losses through direct feeding damage and the transmission of disease-causing organisms. Since the environmental conditions required for mushroom production also favour pest multiplication, growers must adopt a proactive approach emphasizing prevention rather than cure. The integration of sanitation measures, pasteurization procedures, monitoring techniques, biological control agents and judicious use of approved pesticides provides an effective framework for sustainable pest management. Through the adoption of integrated pest management strategies, mushroom growers can enhance productivity, improve product quality and ensure the long-term viability of mushroom cultivation as a profitable enterprise.

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Volume: 06 Issue No: 10

CULTIVATION PRACTICES AND STATUS OF AONLA IN RAJASTHAN

Article ID: AG-VO6-I10-58

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Introduction

Aonla (*Emblica officinalis*) cultivation is a major and highly profitable agri-horticultural practice in Rajasthan, particularly across semi-arid and arid zones. Its extreme drought tolerance, resilience against high summer temperatures, and ability to thrive in marginal, saline, or alkaline soils make it perfectly suited for the state's harsh edaphoclimatic conditions. The Jaipur district is officially designated as the "Aonla District" due to its prime position in area and production, though commercial farming is also widespread in Udaipur, Ajmer, Alwar, and Jodhpur.

Climate and Soil Suitability

Temperature Threshold: Can tolerate scorching heat up to 46°C during May–June.

Soil Flexibility: Thrives in sandy loam to light clay soils. It exceptionally tolerates a high soil pH range of 6.5 to 9.5, making it a preferred choice for Rajasthan's saline-alkali wasteland reclamation.

Water Table Resilience: Avoid heavy soils with poor drainage or areas prone to high water logging.

Prominent Varieties for Rajasthan

Goma Aishwarya: A highly drought-hardy selection specifically developed and released for arid regions by the

NA-7 (Narendra Aonla-7): Widely preferred by local farmers for its prolific bearing and low susceptibility to fruit necrosis.

Krishna & Kanchan: Exceptional commercial varieties for high-quality table use and industrial pulp processing.

Chakaiya: A late-maturing, highly productive alternate-year bearer popular in mixed orchards.

Core Agronomic Practices

1. Propagation and Field Establishment

Propagation Technique: Commercial orchards strictly use patch budding performed on 6-month to 1-year-old local deshi rootstocks from June to September to ensure quick establishment before the dry season.

Pit Preparation: Dig 1m × 1m × 1m pits during May–June. Fill each pit with topsoil mixed with 20–30 kg of well-decomposed Farmyard Manure (FYM) and 5–8 kg of Gypsum to counteract soil alkalinity.

Spacing: Standard square layout spacing is maintained at 6m × 6m or 8m × 8m.

2. Water and Nutrient Management

Drip Irrigation: Highly recommended across Rajasthan to conserve water. Young plants need regular watering at 7–10 day intervals during summer. Mature trees need restricted watering during flowering (March) but regular irrigation during fruit development (July–November).

Mulching: Use organic crop residue like paddy straw, local mustard straw, or plastic mulch around the basin to cut down evaporation and conserve soil moisture.

Nutrients: Apply 10–15 kg FYM per plant for 1-year-old trees, increasing by 10 kg every year up to 50–60 kg for mature trees, supplemented with Nitrogen, Phosphorus, and Potassium after fruit set.

3. Canopy Training and Pruning

Training System: Trees are shaped using the Modified Central Leader System. Train the trunk to a clear height of about 75–100 cm, keeping 4–6 well-spaced main scaffold branches.

Pruning: Regular heavy pruning is not required. Annually clear out dead wood, crossing, weak, or pest-infested branches right after harvesting in January–February.

Plant Protection & Harvesting

Key Pests: Bark eating caterpillar and Shoot gall maker are prominent in Rajasthan. Manage them by clean cultivation and direct chemical spraying into active boreholes.

Key Diseases: Aonla Rust causes premature leaf and fruit drop. Treat with wet sulfur or systemic fungicides.

Harvesting Strategy: Collect fruits by individual hand picking using ladders between November and January. Avoid shaking the tree branches, as fallen fruits get bruised, inviting soil-borne rot during storage.

Importance of Aonla cultivation

Aonla (*Emblica officinalis*) is highly valued across India for its robust economic returns, therapeutic properties, and industrial adaptability. It serves as an ideal crop for sustainable farming in challenging climates like Rajasthan.

High Economic Returns & Wasteland Utilization

High Yield: A mature tree can yield 100 to 200 kg of fruit annually, providing stable long-term income for 40 to 50 years.

Low Input Cost: The crop demands minimal water, fertilizers, and intensive management compared to other commercial fruit trees.

Wasteland Utilization: It grows exceptionally well in marginal lands, ravines, and saline-alkali soils (pH **6.5 to 9.5**) where other crops fail.

Nutritional and Medicinal Value

Vitamin C Powerhouse: Aonla is one of the richest natural sources of Vitamin C (Ascorbic acid), containing up to 600–700 mg per 100g of pulp.

Antioxidant Properties: Packed with tannins, polyphenols, and gallic acid, it neutralizes free radicals and boosts human immunity.

Ayurvedic Staple: It is a foundational ingredient in traditional Indian medicine, including formulation of Chyawanprash, Triphala, and diverse hair oils.

Industrial and Processing Potential

Diverse Product Range: Fresh fruits are processed into high-value items like pickles, murabba (sweet preserve), candies, juices, and dried powder.

Long Shelf Life Products: While fresh fruits are highly perishable, processed products have an extended shelf life, reducing post-harvest losses.

By-Product Utilization: Extracts are heavily consumed by the global cosmetic, pharmaceutical, and nutraceutical industries for anti-aging and wellness products.

Environmental and Ecological Benefits

Drought Resilience: Its deep taproot system makes it highly drought-hardy, adapting well to the changing climatic patterns of arid zones.

Soil Reclamation: Regular leaf fall adds organic matter to the soil, while the plant's root tolerance helps in biological reclamation of sodic soils.

Intercropping Flexibility: Its deciduous nature (shedding leaves in spring) allows farmers to successfully grow winter intercrops like pulses and medicinal plants.

Fruit Quality of Aonla

The commercial value and grade of Aonla fruit are determined by distinct physical and biochemical quality parameters. These metrics fluctuate significantly based on the chosen cultivar, growing soil conditions, and precise harvest timing.

Understanding these metrics ensures optimal industrial returns for processing or raw market distribution.

Physical Quality Metrics: Physical dimensions define the structural grading of the fruit, directly impacting market valuation and food processing equipment design.

Fruit Weight: Ranges between 25g to 55g per fruit. Varietal outliers like *Laxmi-52* can cross 52g, whereas smaller varieties lean closer to 25g–30g.

Shape & Dimensions: Fruit shape registers as spheroid to oblate. Average vertical diameter metrics hover around 3.2 to 4.7 cm, with horizontal diameters spacing up to 5 cm.

Pulp-to-Seed Ratio: Higher pulp percentages translate to greater industrial value. Quality fruits maintain a 90% to 94% pulp recovery rate, leaving seed weight at a minimal 1.5g to 2.4g.

Crude Fiber: Commercial grades prefer lower fiber values (0.5% to 1.6% in raw pulp) to prevent unappealing textures in processed candies, juices, and preserves.

Biochemical Quality Metrics: Biochemical density establishes the genuine nutritional superiority and bitter-sour flavor matrix characteristic of the fruit.

Ascorbic Acid (Vitamin C): The defining therapeutic benchmark, ranging from 300 mg up to 900 mg per 100g of fresh pulp. Elite cultivars like *NA-6* exhibit consistently peak levels across harvest cycles.

Total Soluble Solids (TSS): Measures natural sugar density via brix concentration. It elevates as the fruit reaches absolute peak maturity, ranging between 9° Brix and 13° Brix.

Titratable Acidity: Ranging from 1.2% to 2.8%. Higher acidity levels help naturally preserve value-added commodities like *murabba* and pickles.

Total Phenols & Tannins: Responsible for the unique astringent taste. Rich content includes polyphenols and hydrolysable tannins (*emblicanin A and B*) which generate exceptional anti-aging and antioxidant profiles.

Intercropping Friendly: The open canopy allows farmers to cultivate winter legumes, grains, or medicinal plants between rows

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: 10

CULTIVATION PRACTICES AND ROLE OF LASODA IN RAJASTHAN

Article ID: AG-VO6-I10-59

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Introduction

The cultivation methods of Lasoda (*Cordia myxa L.*) in Rajasthan focus on establishing a hardy root system that can withstand high temperatures, high soil pH, and prolonged drought. Moving away from wild harvesting, commercial growers utilize a systematic approach optimized for the state's semi-arid regions.

1. Land Preparation and Field Layout

Pit Digging: Dig pits of 1m × 1m × 1m dimensions during the hot months of May and June. Sunlight naturally sterilizes the soil against pathogens.

Pit Mixture Configuration: Mix the excavated topsoil with 25–30 kg well-rotten Farmyard Manure (FYM), 2.5 kg Neem cake (to prevent termites), and 50g of Single Super Phosphate (SSP).

Orchard Spacing: Maintain a standard grid layout of 6m × 6m (277 plants/hectare) for high-yielding cultivars, or 8m × 8m (156 plants/hectare) for agroforestry boundaries.

2. High-Tech Propagation

Elimination of Seed Sowing: Commercial farming avoids direct seed sowing because it results in highly variable fruit sizes and late bearing.

Patch Budding Method: Propagate by patch budding in July–August. Bud superior scions (from varieties like *Maru Samridhi* or *Thar Bold*) onto 9 to 12-month-old local wild *deshi* Lasoda rootstocks.

Planting Window: Transplant budded saplings into field pits at the onset of the monsoon (July to September) for high survival rates.

3. Canopy Training and Pruning

Trunk Stabilization: Lasoda has a naturally drooping growth habit. Stake young plants and trim lower shoots to train a strong, straight trunk up to a height of 1 meter.

Framework Development: Allow 4–5 well-spaced main branches to develop into a balanced, open crown using the Modified Central Leader System.

Annual Pruning: Prune right after harvest (May–June) or in the winter dormant phase. Remove exhausted fruiting twigs, crisscrossing branches, and water sprouts to ensure sunlight penetrates the inner canopy.

4. Water Regulation (The Stress Trick)

Young Plant Irrigation: Water young saplings at 7–10 day intervals during summer and 15–20 day intervals in winter.

The Winter Dry Spell: For bearing trees, completely halt irrigation from October to January. This deliberate moisture stress forces uniform leaf drop and dormancy.

Spring Resumption: Resume irrigation in February. This sudden shift triggers massive, uniform flowering and efficient fruit set.

5. Nutrition Schedule

Monsoon Dose: Apply 30–50 kg FYM per mature tree with the arrival of the monsoon rains (July).

Flowering Dose: Supplement with 100–150g Nitrogen, 80g Phosphorus, and 100g Potassium per mature tree in February to maximize fruit development and prevent early fruit drop.

6. Harvesting and Post-Harvest Economics

Harvesting Window: Pick the fruits between April and June when they are mature, hard, and shiny green.

The Maturity Trap: Do not let the fruits turn yellowish-translucent on the tree. Once they soften, they become highly mucilaginous (sticky) and sweet, making them completely unmarketable as a vegetable or pickle raw material.

Yield Output: Budded trees start bearing in their 3rd year, producing 20–30 kg per tree. Yields scale up to 80–100 kg per tree by the 7th to 8th year

Importance of Aonla cultivation

Lasoda (*Cordia myxa L.*), traditionally a wild tree, is now cultivated commercially as a highly profitable, climate-resilient crop across dry regions.

Its ability to grow in poor soils and survive intense heat makes it a valuable asset for sustainable farming.

The primary factors driving the importance of Lasoda cultivation include:

High Economic Returns & Market Demand

Premium Market Value: Unripe, hard green fruits harvested early in the season (April–May) fetch excellent wholesale prices as a popular vegetable and the primary ingredient in Rajasthani pickle (*Gunda Achar*).

Early Commercial Bearing: While wild trees take up to 7 years to fruit, modern budded cultivars (like *Maru Samridhi*) yield commercial harvests by the 3rd year.

Prolific Multi-Decade Yields: A single mature, well-managed tree produces 80 to 100 kg of fruit annually, providing stable income for 50 to 60 years.

Minimal Input Cost: The crop is naturally resilient to major pests and diseases, keeping maintenance and chemical expenses exceptionally low.

Nutritional and Therapeutic Value

Nutrient Dense: The fruits are rich in essential carbohydrates, proteins, calcium, phosphorus, and iron, acting as a vital food source in arid regions.

Natural Antioxidants: The pulp features high concentrations of total phenolics, flavonoids, and natural mucilage, offering anti-inflammatory and digestive benefits.

Traditional Medicine: The bark, leaves, and fruits are actively used in Ayurveda and Unani systems to treat coughs, throat infections, and respiratory ailments.

Climate Resilience & Wasteland Utilization

Extreme Heat Tolerance: The tree comfortably withstands scorching summer temperatures up to **48°C**, making it highly reliable under changing climate patterns.

Drought Hardiness: Its deep and expansive taproot system allows it to survive on minimal water and thrive in low-rainfall zones.

Soil Reclamation: It grows successfully in marginal, rocky, sandy, and saline-alkaline soils where standard fruit crops cannot survive.

Agroforestry and Farming System Benefits

Effective Windbreaks: Thanks to its dense, spreading canopy, planting Lasoda along farm boundaries shields sensitive crops from hot summer winds (*loo*) and limits shifting sand dunes.

Intercropping Compatibility: Its mandatory winter dormancy (October to January) causes complete leaf drop, opening the canopy to allow successful cultivation of winter (*Rabi*) crops like mustard, cumin, or pulses.

Soil Improvement: Heavy annual leaf shedding adds substantial organic biomass to the ground, naturally improving topsoil texture and nutrient status over time

Fruit Quality of Lasoda

The fruit quality of **Lasoda** (*Cordia myxa L.*, also known as Gunda or Lehsua) is evaluated based on distinct physical and chemical parameters. Because it is consumed both as an unripe green vegetable/pickle and as a ripe medicinal table fruit, its quality profile changes drastically depending on the harvest stage.

Physical Quality Metrics

Physical size and pulp mass directly dictate the grading and commercial market value of Lasoda in wholesale yards.

Fruit Weight & Sizing: Fresh individual fruit weight ranges between 6g to 15g depending on the cultivar. Improved commercial varieties are specifically bred for larger, bolder fruit.

Pulp-to-Stone Ratio: A high pulp-to-stone ratio is the primary indicator of elite fruit quality. Standard wild varieties have large stone seeds, while premium cultivars like *Maru Samridhi* boast a pulp-to-stone ratio of up to 9.26, minimizing waste during seed removal.

Viscous Mucilage: Unripe fruits contain a thick, highly sticky, translucent mucilage inside the cavity. While tedious to process, this mucilage contains high concentrations of natural pectins, giving the fruit its famous structural crunch when pickled.

Biochemical & Nutritional Profiles

Lasoda fruits are widely recognized as nutritional and antioxidant gold mines suited for functional food development.

Moisture & Protein: Fresh ripe fruits contain roughly 82.5% moisture and are notably higher in natural plant proteins (1.8% to 2.2%) compared to standard commercial tree fruits.

Total Soluble Solids (TSS) & Acidity: In the early green stage, the TSS is low while organic acidity is higher. As the fruit fully ripens, it undergoes a chemical shift—the skin turns pinkish-golden, starch converts to sugar, and the TSS rises sharply, making the pulp sweet and mucilaginous.

Phytochemical Diversity: The fruit pulp is heavily dense with health-promoting bioactive compounds. It features rich profiles of tannins, flavonoids, phenolic acids, saponins, and terpenes, which give the fruit its strong anti-inflammatory and gastroprotective qualities. Mineral Concentrations: It is a rich, natural source of essential minerals like Calcium, Phosphorus, Iron, and Zinc, serving as a vital nutritional security crop in dry geographic zones.

Fruit Quality Standouts by Variety

Commercial performance evaluations by institutes like ICAR-CAZRI, Jodhpur highlight distinct varietal quality advantages:

Cultivar Variety	Specific Fruit Quality Advantage	Best Market Application
Maru Samridhi	Top pulp-to-stone ratio (9.26); high edible pulp yield.	Premium *Gunda Achar* (pickles) and processing.
Karan Lasoda	Produces the longest and largest physical fruit dimension (avg. 24.34 mm).	Fresh market bulk vegetable sales.
Thar Bold	Exceptionally bold, heavy fruit weight with high heat resilience.	High-yielding commercial orchards in extreme desert zones.

Harvest Quality Traps: Vegetable vs. Ripe Stage

Maintaining strict harvesting discipline is essential to preserving the desired fruit quality:

The Vegetable/Pickle Stage (Premium Value): Fruits must be harvested when they are completely hard, shiny green, and unripe. This preserves the internal mucilage structure required for pickling.

The Ripe Stage (Medicinal Value): If left on the tree, fruits turn a yellowish-translucent or pinkish-golden hue. The flesh becomes soft, heavily sticky, and sweet. At this stage, they lose all vegetable market value but are harvested for Ayurvedic lung/cough remedies or sun-dried as *Sukha Saag*.

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: 10

FARMING SYSTEM AND UTILITY OF BAEL IN RAJASTHAN

Article ID: AG-VO6-I10-60

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Introduction

Bael (*Aegle marmelos*), also known as Wood Apple, Bilva, or Bengal Quince, is rapidly emerging as a highly profitable, climate-resilient fruit crop in Rajasthan. Its extreme tolerance to drought, capacity to survive scorching summer temperatures up to 48°C, and ability to thrive in degraded, saline-alkaline soils make it an ideal choice for the state's arid and semi-arid landscape. The crop faces minimal risk from stray cattle or wild animals because its leaves and bitter rind are naturally unpalatable to them, making it a highly secure investment for farmers.

Present Status and Growing Belts in Rajasthan

Commercial Shift: Bael was traditionally grown as a scattered tree near temples or in home gardens. Today, commercial orchards are thriving across Jaipur, Tonk, Ajmer, Sawai Madhopur, Bharatpur, Alwar, and parts of the Udaipur division.

High Processing Demand: The fruit is heavily sought after by processing units for making Bael powder, squash, candy, and traditional Ayurvedic medicines, creating a reliable domestic market.

Institutional Support: High-yielding, drop-resistant varieties have been extensively trialed and recommended for Rajasthan's soils by institutes like the ICAR-Central Institute for Arid Horticulture (CIAH), Bikaner and Jobner Agriculture University (SKNAU).

Top Bael Varieties for Rajasthan: Farmers should strictly avoid planting seed-grown trees and instead choose high-yielding, thin-shelled budded varieties:

Thar Divya: Developed specifically for hot, arid regions by ICAR-CIAH, Bikaner. It is an early-maturing variety with a thin shell, low fiber content, and excellent pulp quality.

Thar Shivani: Another superior selection from CIAH Bikaner, known for its large fruit size, high pulp recovery, and excellent tolerance to drought stress.

Narendra Bael-5 & NB-9: Released by NDUAT, Ayodhya, these varieties perform exceptionally well in the semi-arid soils of Eastern Rajasthan. They feature a thin shell, few seeds, and high sweetness (TSS).

CISH B-1 & CISH B-2: High-yielding selections from CISH, Lucknow, which are highly successful in commercial block plantations across Jaipur and Alwar districts.

Key Cultivation Methods

1. Land Preparation and Spacing

Pit Digging: Dig pits of 1m × 1m × 1m size during May–June. Let the intense summer sun solarize the pits to destroy soil-borne pathogens.

Pit Filling Mixture: Fill each pit with a mix of topsoil, 20–30 kg of well-decomposed **Farmyard Manure (FYM)**, 2 kg Neem cake (for termite protection), and 50g of Trichoderma powder. If the soil is highly alkaline (sodic), add 3–5 kg of Gypsum per pit.

Orchard Layout: Maintain a standard square spacing of 6m × 6m (277 plants/hectare) or 8m × 8m (156 plants/hectare) for lower-rainfall tracts.

2. Advanced Propagation and Planting

Patch Budding: Commercial farming relies entirely on patch budding performed in June–July. Superior scions are budded onto 1-year-old local *deshi* Bael rootstocks.

Planting Window: Transplant the budded saplings into the field pits at the onset of the monsoon (July to September) to ensure maximum root establishment before the dry winter arrives.

3. Strategic Water & Nutrient Management

Young Plant Care: Water young saplings at 7–10 day intervals during the dry summer months. Once the tree establishes its deep taproot system (after 3–4 years), it requires very little water.

The Summer Deciduous Phase: Bael naturally sheds its leaves during April–May when the fruits are fully mature. Irrigation must be restricted during this period to prevent fruit cracking and encourage natural leaf drop.

Fertilizer Dose: Apply 30–40 kg FYM per mature tree along with 100g Nitrogen, 60g Phosphorus, and 100g Potassium right after the onset of the monsoon (July) to boost the upcoming flowering cycle.

4. Canopy Management

Initial Training: Train the young tree to a clear trunk height of 75–100 cm from the ground using a modified central leader system.

Pruning Window: Clean out dead, dry, crisscrossing branches, and water sprouts annually during May–June when the tree is naturally leafless after harvest.

Harvesting and Post-Harvest Economics

Gestation Period: Budded Bael trees start bearing commercial fruits from the 4th to 5th year of planting, whereas seed-grown trees take up to 8–10 years.

Yield Expectation: A mature, well-managed 10-year-old budded tree yields anywhere between **150 to 250 fruits annually** (approx. 100–150 kg of fruit weight per tree).

Harvesting Technique: Bael fruits take nearly 10 to 11 months to mature on the tree. Harvest them between April and June when the rind color changes from deep green to a yellowish-green tinge. Always pick the fruit with a small portion of the stem attached to prevent fungal rot at the stalk end.

Importance of Bael Farming

Bael (*Aegle marmelos*) farming has emerged as a highly profitable and sustainable agricultural choice, especially for arid and semi-arid regions. Its exceptional ability to thrive on neglected, marginal lands while producing premium-value fruits makes it an ideal crop for modern climate-resilient farming.

The primary reasons behind the growing global and domestic importance of Bael cultivation include:

Exceptional Profitability and Wasteland Utilization

Sodic Land Reclamation: Bael thrives exceptionally well in degraded, sandy, and saline-alkaline soils with a high pH range of 6.5 to 9.0, turning unproductive barren land into a profitable asset.

Low Initial Investment: The crop demands minimal expenses for chemical fertilizers, expensive field preparations, or continuous management compared to traditional fruit crops.

Stray Animal Immunity: The bitter, woody rind of the fruit and the aromatic compounds in the leaves make Bael naturally unpalatable to stray cattle and wild animals, eliminating the need for expensive perimeter fencing.

Long-Term Stable Income: A single mature budded tree can produce 150 to 250 fruits annually, providing a secure, consistent revenue stream for over 60 years.

High Therapeutic, Medicinal, and Nutritional Value

Gastrointestinal Remedy: Bael is globally recognized as one of the best natural cures for chronic diarrhea, dysentery, and irritable bowel syndrome (IBS) due to the presence of natural tannins and mucilage.

Nutritional Powerhouse: The golden pulp is loaded with essential vitamins, including a very high concentration of Riboflavin (Vitamin B2), along with substantial amounts of Vitamin A, Vitamin C, Calcium, and Phosphorus.

Ayurvedic Core Ingredient: It is a foundational component of traditional Indian medicines, serving as a primary root ingredient in the classical "Dashmula" formulation and various immunity-boosting tonics.

Massive Industrial and Processing Demand

Zero Post-Harvest Waste: The hard, woody shell of the fruit protects it from bruising during transit, resulting in near-zero post-harvest transport losses.

Diverse Product Ecosystem: The pulp is highly sought after by food processing units to create value-added consumer products like Bael powder, concentrated squash, candies, preserves (*murabba*), and fruit bars.

Cosmetic and Timber Use: Essential oils extracted from Bael leaves and twigs are widely used in the premium cosmetic industry for antibacterial skincare products, while the aromatic wood is valued for specialized carvings.

Climate Resilience & Eco-Friendly Agroforestry

Extreme Weather Tolerance: The tree easily withstands blistering summer heat waves up to **48°C** and severe water scarcity by utilizing its deep, extensive taproot system.

Strategic Intercropping: Bael naturally sheds its leaves during April and May, entering a brief dormant phase. This open canopy lets ample sunlight reach the ground, allowing farmers to successfully cultivate winter (*Rabi*) pulses, oilseeds, or medicinal herbs between the tree rows.

Carbon Sequestration: The dense root network stabilizes fragile topsoil in wind-heavy regions, preventing soil erosion while contributing to long-term carbon storage in dry agricultural zones.

Fruit Quality of Bael

The commercial grade, processing efficiency, and therapeutic value of Bael fruit (*Aegle marmelos*) are determined by a precise mix of physical and biochemical traits. Unlike standard fruits, high quality in Bael means having a thin shell, minimal seeds, and low sticky fiber inside the pulp.

Physical Quality Characteristics: Physical metrics define the grading and determine how easy the fruit is to transport and process mechanically.

Fruit Weight & Sizing: Varies drastically from 350g to over 2 kg. For commercial market distribution, medium-to-large uniform weights (approx. 1 kg to 1.5 kg) are highly preferred.

Shell (Rind) Thickness: Ranging from 0.15 cm to 0.30 cm. Industrial buyers look for a thin rind (under 0.20 cm) because it cracks easily during processing, reducing handling costs.

Pulp Recovery Rate: High-quality cultivars yield a 65% to 75% total edible pulp recovery. The pulp should feature a rich, attractive light-yellow to deep-orange hue.

Seed and Mucilage Cavities: Seeds are packed inside pockets of highly sticky, clear mucilage. Quality fruits minimize seed counts (fewer than 100-120 per fruit) to prevent the pulp from tasting bitter during extraction.

Fiber Texture: Low to medium fiber content (3% to 5%) is essential. Fine, soft fibers make the pulp perfect for preparing smooth squashes, fruit slabs, and beverages.

Biochemical & Nutritional Characteristics: The chemical composition of Bael establishes its premium medicinal value and unique aromatic profile.

Total Soluble Solids (TSS): Bael features one of the highest sugar/solute concentrations among tree fruits, ranging from 28° Brix to as high as 44° Brix in elite genotypes. High TSS means rich natural sweetness, which reduces the amount of extra sugar needed during processing.

Riboflavin (Vitamin B2) Density: Bael is recognized as an unmatched natural source of **Riboflavin**, providing vital support for human energy pathways and cellular health.

Titratable Acidity: Maintains a naturally low, mild acid profile ranging between 0.30% and 0.50%. This creates an ideal, balanced sweet-to-sour flavor profile.

Bioactive Compounds: The pulp is densely packed with marmelosin, tannins, coumarins, and **phenolic acids**. These specialized phytochemicals give Bael its highly sought-after digestive, anti-inflammatory, and therapeutic properties.

Varietal Quality Performance Standouts: Specific improved cultivars exhibit unique quality advantages under dryland farming:

Cultivar Variety	Specific Fruit Quality Advantage	Primary Use Case
Thar Divya	Very early ripening (270 days), thin shell (0.19 cm), exceptionally high pulp TSS (38.75° Brix), fine fiber.	High-end processing, dried powders, and ready-to-serve (RTS) juices.
Narendra Bael-7 (NB-7)	Heaviest individual fruit weight, excellent pulp ratio (~70%), completely low fiber.	Premium retail market display and large-scale *murabba* (preserves).
CISH Bael-1	Exceptional sugar concentration and high TSS (~39.69° Brix).	Industrial pulp concentrates and sweet candies.
Goma Yashi	Appropriate uniform size, low seed layout, bright yellow visually appealing pulp.	Commercial beverage manufacturing.

Indicators of Peak Harvest Quality: To maintain elite fruit quality and prevent fruit cracking on the branches, harvest when the following indicators align:

1. **Color Transition:** The hard rind changes from a dark, matte green to a distinct light yellowish-green or lemon-yellow tinge.
2. **Natural Leaf Shedding:** The tree naturally drops its leaves during April–May, signaling that the nutrients have fully moved into the developing fruit crop.
3. **Stalk Attachment:** The fruit must be harvested with a small portion of the stem twig attached; pulling it off cleanly leaves a hole that invites fungal pathogens during storage.

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: 10

DIGITAL AQUACULTURE: INTEGRATION OF IOT, ARTIFICIAL INTELLIGENCE AND AUTOMATION FOR PRECISION FISH FARMING

Article ID: AG-VO6-I10-61

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Abstract

Aquaculture is entering a new technological era. Conventional fish farming depends strongly on farmer experience, visual observation and periodic water-quality measurements. Digital aquaculture combines sensors, the Internet of Things (IoT), Artificial Intelligence (AI), machine learning, computer vision, cloud or edge computing and automation to continuously observe culture conditions, interpret information and support timely management decisions. This article explains, in an accessible popular-scientific format, how these technologies can transform fish farming from reactive management to precision production. Applications in water-quality monitoring, intelligent feeding, fish behaviour, biomass estimation, disease-risk detection, biofloc and recirculating systems are discussed, together with limitations and future prospects.

Keywords: Internet of Things, Artificial Intelligence, sensors, machine learning, computer vision.

Introduction

Aquaculture has developed from traditional, experience-based fish farming into increasingly intensive production systems. As stocking densities and production targets rise, the farmer must manage many variables at the same time. Temperature, dissolved oxygen, pH,

salinity, ammonia, feeding, biomass, fish behaviour and disease risk can change continuously. A measurement taken once in the morning cannot always describe what is happening in a pond several hours later.

Digital aquaculture offers a new approach. Instead of depending only on periodic observations, a smart farm can continuously collect information through sensors and cameras. IoT technologies transmit the information, artificial intelligence interprets patterns, and automated equipment can respond to changing conditions. The farmer remains central to the process, but decisions are supported by a much richer and more continuous stream of information.

When the Pond Starts to 'Speak'

Imagine a farmer inspecting a pond at 6:00 in the morning. The fish are active; the water appears normal and feeding is satisfactory. But what happens at 2:00 in the afternoon when temperature rises and dissolved oxygen begins to decline? What happens at midnight when fish and microorganisms continue to consume oxygen? In a conventional system, these changes may remain unnoticed until the next inspection.

In an IoT-enabled farm, sensors can continuously monitor temperature, dissolved oxygen, pH, salinity, turbidity and water level. The data can be transmitted to a mobile phone, computer or cloud platform. A farmer can therefore see not only the present condition but also the trend over time. This makes it possible to identify gradual deterioration before it develops into a major production problem.Sensors: The Eyes and Ears of the Digital Farm

Sensors form the foundation of digital aquaculture. A dissolved oxygen probe can record oxygen concentration continuously, while temperature and pH sensors provide information about the physical and chemical environment. Conductivity and salinity sensors are useful in brackishwater and marine systems, while turbidity and water-level sensors can support pond and tank management. In more advanced systems, sensors may also monitor oxidation-reduction potential, flow, pressure and specific chemical parameters.

The real value of sensors comes from continuous measurement. A manual observation provides a snapshot; a connected sensor creates a time series. These time-series data can reveal daily cycles, sudden disturbances and relationships between environmental conditions and fish performance. Sensor reliability is therefore critical, and regular calibration, cleaning and protection against biofouling are essential.

Examples of Sensors Used in Aquaculture Farms

Sensor	Parameter monitored	Typical application in aquaculture
Temperature sensor	Water temperature (°C)	Fish/shrimp growth, metabolism and feeding management
Dissolved Oxygen (DO) sensor	DO (mg/L)	Aerator control, oxygen management and prevention of hypoxia
pH sensor	pH	Monitoring acidity/alkalinity and maintaining suitable culture conditions
Salinity sensor	Salinity (ppt/PSU)	Shrimp, seabass and other brackish/marine species
Electrical Conductivity (EC) sensor	Conductivity	Estimation of dissolved ionic content and salinity
Turbidity sensor	Water turbidity (NTU)	Monitoring suspended solids, plankton and water clarity
Ammonia sensor	NH_3/NH_4^+	Detection of toxic ammonia accumulation
Nitrite sensor	NO_2^-	Monitoring nitrogen toxicity, especially in intensive systems
Nitrate sensor	NO_3^-	Monitoring nitrogen accumulation in recirculating systems
ORP sensor	Oxidation–reduction potential (mV)	Monitoring microbial activity and water oxidation status
Water-level sensor	Water depth/level	Automatic water addition, drainage and flood/overflow protection
Flow sensor	Water flow rate	Monitoring pumps, recirculation and water exchange
Pressure sensor	Water/air pressure	Pump, filtration and aeration-system monitoring
Light sensor	Light intensity (lux/PAR)	Monitoring photoperiod and

		algal/plant production
Weather sensor	Temperature, humidity, rainfall, wind speed etc.	Outdoor pond environmental monitoring
Rain sensor	Rainfall	Automatic adjustment of farm operations during heavy rainfall
Ultrasonic sensor	Feed/water level or biomass-related measurements	Feed-bin monitoring and non-contact level measurement
Camera/vision sensor	Fish/shrimp behaviour and biomass	AI-based feeding, counting, size estimation and health monitoring
Hydrophone/acoustic sensor	Sound/acoustic activity	Behaviour monitoring and feeding/activity assessment
Accelerometer/IMU sensor	Movement/vibration	Monitoring fish behaviour or mechanical equipment
Gas sensor	CO_2 and other gases	Monitoring gas accumulation, especially in RAS/biofloc systems
Chlorophyll sensor	Chlorophyll-a	Estimation of phytoplankton/algal biomass
Total suspended solids (TSS) sensor	Suspended solids	Monitoring solids accumulation in RAS and intensive culture

Commercially available Sensors

Company / Product	**Main parameters**	**Type**
YSI ProDSS	DO, temperature, pH, conductivity, salinity, ORP etc.	Portable multiparameter
YSI ProSolo	DO, temperature, conductivity, salinity	Portable
YSI ODO RTU	DO, temperature	Continuous sensor
YSI IQ SensorNet	DO, pH, conductivity, turbidity, ammonium, nitrate etc.	Online monitoring network
Hanna HI98194	pH, ORP, EC, TDS, salinity, DO, temperature	Portable multiparameter
Hanna HI83303	Alkalinity, calcium, nitrite, phosphate and other parameters	Aquaculture photometer
HORIBA U-50	pH, DO, conductivity, salinity, temperature, turbidity etc.	Portable multiparameter
HORIBA H-1 Series	pH, DO, conductivity, turbidity etc.	Fixed/continuous

Atlas Scientific sensors	pH, DO, EC, ORP, temperature etc.	Sensor modules
Bluelab Guardian Monitor	pH, conductivity, temperature	Continuous monitor
Hanna HI98190	pH/ORP and temperature	Portable

Artificial Intelligence: Turning Data into Understanding

Sensors can tell us what is happening, but Artificial Intelligence can help answer a more difficult question: what is likely to happen next? A fish farm can generate thousands of observations during a single production cycle. Machine-learning models can analyze relationships among temperature, oxygen, feed intake, biomass, growth and behaviour that may be difficult to recognize through manual observation.

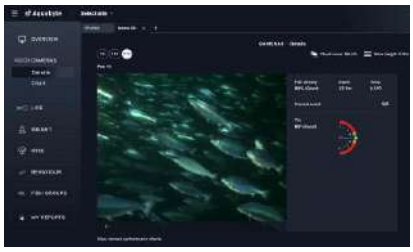
For example, a model can be trained to estimate fish biomass from historical growth, feeding and environmental information. Other models can predict water-quality changes or identify patterns associated with reduced feeding activity. Such predictions can support management before a problem becomes visible.

Commercial AI solutions for fish farming

Commercial system/company	**AI application**	**What it does**
Aquabyte	Computer vision + AI	Estimates fish weight, biomass and growth; monitors behaviour and welfare; detects sea lice; supports feeding decisions
Tidal	AI + computer vision + autonomous camera	Monitors feeding, growth, health and welfare; provides AI-powered autonomous feeding
Observe Technologies	AI decision-support	Analyses farm data from cameras, sensors and other systems; provides feeding recommendations and anomaly alerts
Umitron	AI/IoT smart feeding	Uses fish behaviour and environmental data to optimize feeding
eFishery	Intelligent automatic feeding	Automated feeding using data-driven feeding control
AQ1 Systems	Acoustic/AI feeding technology	Uses fish-feeding behaviour to control feeding in aquaculture
Eruvaka Pond Mother	IoT + analytics	Monitors pond parameters and supports automated farm management and feeding
Computer-vision feeding systems	Deep learning	Detect fish activity/feeding behaviour and determine when feeding should stop or continue

Computer Vision: Making Fish Behaviour Measurable

One of the most exciting developments in digital aquaculture is computer vision. Cameras can continuously observe fish without repeatedly catching or handling them. Image-processing and deep-learning techniques can be used to estimate fish size, count fish, measure activity, assess feeding behaviour and identify unusual movement patterns.

Aquabyte – SYSTEM / Hammerhead / HYDRA 360





Innovasea– BiomassPro

To a human observer, a group of hundreds of fish may simply appear as a moving mass. To a trained computer-vision model, the same movement can become measurable information. Swimming speed, aggregation, feeding activity and changes from a normal behavioural pattern can potentially be converted into signals for farm management.

Commercial computer-vision systems for aquaculture

Company / system	Computer vision application
Aquabyte – SYSTEM / Hammerhead / HYDRA 360	Underwater stereo/360° vision + AI
Innovasea – BiomassPro	AI-powered stereo camera
Innovasea – Underwater Cameras	HD underwater vision
Observe Technologies / AKVA observe	AI analysis of vision + farm data
AquaVyon	Computer vision + underwater cameras
Tidal	Computer vision + underwater cameras
Umitron	AI/computer vision + IoT

The Intelligent Feeder: Teaching Machines to Understand Fish Appetite

Feed is one of the largest recurring costs in intensive aquaculture. Too little feed can reduce growth, while excessive feed increases cost and contributes to water-quality deterioration. Fixed feeding schedules cannot always account for changes in appetite caused by temperature, oxygen concentration, biomass, health or environmental stress.

AI-based feeding systems attempt to make feeding responsive to the fish. Cameras can record feeding behaviour, software can analyze the response, and the system can modify the

feeding rate. The goal is not merely to automate the delivery of feed, but to deliver an amount that is better matched to actual fish demand.

Commercial automatic fish feeders

Commercial product/company	Feeding technology	Typical application
Arvo-Tec T Drum 2000	Programmable drum/dosing feeder	Hatcheries, tanks, ponds and cages
Arvo-Tec Feeding Robot	Automated mobile robot	RAS and indoor fish farms
Arvo-Tec Centralized Feeding System	Pneumatic centralized feed delivery	Large commercial farms
AKVA Group Smart Feeding	Automated + precision feeding	Marine cages and land-based farms
Pentair AES Pond Feeders	Programmable automatic feeding	Ponds and aquaculture facilities
FIAP Automatic Feeders	Timer-controlled dispensing	Ponds, tanks and hatcheries
eFishery intelligent feeder	IoT-based automated feeding	Pond aquaculture
Umitron	AI/IoT feeding system	Commercial fish farms
Fish Mate P21	Programmable pond feeding	Small ponds
Jebao FD series	Programmable automatic feeding	Outdoor ponds/small farms



Arvo-Tec T Drum 2000



eFishery automatic feeder



Skretting auto feeder

From Warning to Action: Automation in Aquaculture

The final step in a digital system is automation. Suppose dissolved oxygen falls below a predetermined operational threshold. In a conventional farm, a person must detect the problem

and switch on an aerator. In an automated system, the sensor sends the information to a controller, the controller activates the aerator and the system continues to monitor the response. Similar principles can be applied to feeders, pumps, valves, water-exchange systems and other equipment.

Automation is particularly useful for repetitive tasks and for situations in which a rapid response is important. Nevertheless, automated actions should be designed with safe operating limits, alarms and manual override options. Technology should support responsible farm management rather than remove human supervision.

Digital Aquaculture in Biofloc and RAS Systems

Intensive systems such as biofloc technology and recirculating aquaculture systems provide promising environments for digital monitoring because they depend on relatively controlled and closely managed conditions. Continuous monitoring of dissolved oxygen, pH, temperature, water level and other variables can help maintain system stability.

In a biofloc system, digital records can help researchers examine relationships among carbon input, microbial activity, water quality, feeding and fish growth. In RAS facilities, sensors can be connected to pumps, filtration, aeration and oxygenation systems. The long-term objective is to develop integrated control systems that learn from previous production cycles and progressively improve management decisions.

Can Artificial Intelligence Detect Fish Health Problems?

Fish health is another promising area for digital technologies. Before obvious clinical signs appear, fish may show changes in feeding, swimming, aggregation or activity. Computer vision and machine learning can potentially identify deviations from normal behaviour and generate an early warning.

However, an AI warning should be interpreted as an indicator of possible abnormality, not automatically as a disease diagnosis. Laboratory confirmation remains important whenever a specific pathogen or disease condition must be identified. The most useful role for AI may therefore be early detection and prioritization of tanks or ponds requiring closer investigation.

The Digital Twin: A Virtual Copy of the FarmA more advanced concept is the digital twin: a dynamic digital representation of a real aquaculture system that is continuously updated using real-time data. A digital twin could incorporate tank volume, biomass, temperature, oxygen, feeding, water exchange and growth information. It could then be used to explore hypothetical

situations, such as how increased biomass might affect oxygen demand or how changes in feeding could influence water quality.

What Will the Fish Farm of the Future Look Like?

The fish farm of the future may still contain familiar ponds, tanks, nets and feeders. What will change is the digital layer operating around them. Sensors will continuously collect information, cameras will observe fish, AI systems will analyze patterns, and automated equipment will respond to changing conditions. Farmers may receive information through smartphone dashboards rather than relying only on physical inspection.

This does not mean that farmers will be replaced by machines. The more realistic future is one in which human experience and digital intelligence work together. Farmers will increasingly supervise systems, interpret information, verify unusual events and make strategic decisions, while machines handle repetitive monitoring and control tasks.

Challenges: Technology Alone Is Not Enough

Digital aquaculture has significant potential, but several challenges must be addressed. Sensors operating in water may experience biofouling, corrosion and calibration drift. Rural farms may have unreliable internet connectivity or limited electricity. AI models require large, high-quality datasets, yet species-specific datasets remain limited for many important aquaculture species. A model trained in one farm, climate or camera system may not perform equally well elsewhere.

Cost is another important consideration, especially for small and medium-scale farmers. Technologies must therefore be affordable, robust, easy to maintain and understandable to users. Farmer training, technical support, cybersecurity, data ownership and protection of farm records will also become increasingly important as farms become more connected.

A Major Opportunity for Indian Aquaculture

India has an exceptionally diverse aquaculture sector, ranging from small freshwater ponds and hatcheries to intensive shrimp farms, biofloc units, recirculating systems and marine cages. This diversity creates a strong opportunity for developing digital technologies specifically suited to Indian production conditions.

Future research should emphasise low-cost IoT systems, smartphone-based monitoring, solar-powered sensor networks, edge computing for areas with poor connectivity and AI models

trained on Indian species. Species-specific datasets for Asian seabass, tilapia, Indian major carps and shrimp could support the development of locally relevant predictive tools.

The Road Ahead

The next generation of digital aquaculture will move beyond isolated technologies. IoT, AI, computer vision, robotics, cloud or edge computing, automation and digital twins will increasingly operate as interconnected components. The objective will be to build production systems that can continuously observe themselves, identify emerging risks, recommend appropriate actions and, where appropriate, automatically implement safe responses.

The central concept can be expressed in five words: Sense → Connect → Understand → Predict → Act. Sensors sense the environment. IoT connects the devices. Artificial Intelligence understands patterns. Predictive models anticipate changes. Automation acts on the information. The farmer remains at the centre, using these tools to make informed decisions.

Conclusion

Digital aquaculture represents more than the installation of sensors or automated feeders. It is a change in the way aquaculture is observed, understood and managed. By combining IoT-based monitoring, Artificial Intelligence, computer vision and automation, fish farming can move from largely reactive management towards continuous, predictive and precision-based production.

The ultimate objective is not to make aquaculture more complicated, but to make it more precise, efficient, sustainable and resilient. The pond of the future may look much like today's pond, but beneath the surface a network of sensors, cameras, algorithms and automated systems may be continuously asking one question: 'What does the fish need now—and what is likely to happen next?' That is the promise of digital aquaculture.

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Volume: 06 Issue No: 10

GROW MORE, WASTE LESS: THE POWER OF INTEGRATED CROP MANAGEMENT

Article ID: AG-VO6-I10-62

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Introduction

Farmers are increasingly required to produce more food while managing higher input prices, uncertain weather, water shortages, declining soil quality and recurring pest and disease problems. These challenges cannot always be solved by adding more fertilizer or spraying pesticides more frequently. Lasting improvement depends on making well-planned decisions and coordinating the different operations involved in crop production.

Integrated Crop Management

Integrated Crop Management is the planned coordination of crop-production practices from land preparation and variety selection through crop growth, harvesting, and post-harvest handling. It draws on farmers' experience, scientific recommendations and appropriate modern technologies.

It brings together crop selection, quality seed, soil and nutrient care, water conservation, weed control, pest management, suitable technology and careful harvesting. When these practices are planned as parts of one system, farmers can use available resources more effectively and work towards profitable, resilient and environmentally responsible farming.

Key Practices in Integrated Crop Management

1. Choose Crops and Varieties Suited to Local Conditions

The choice of crop and variety strongly influences the performance of a farming system. Farmers should consider local temperature and rainfall patterns, soil type, irrigation facilities,

length of the growing season, likely pest and disease problems and market demand before making a selection.

Where suitable options are available, varieties with useful tolerance to drought, salinity, pests, or diseases can help reduce production risks. Short-duration varieties may be appropriate when water is limited or the available growing period is brief.

2. Start with Quality Seed and Good Crop Establishment

Healthy, vigorous seed is an essential starting point for a productive crop. Seed with good germination and appropriate physical and genetic purity can help establish a more uniform plant stand. Farmers should obtain seed from dependable sources, read the label carefully, check relevant dates and lot details and use the recommended seed rate.

Seed treatment, when advised for a particular crop and problem, can help protect seed and young seedlings from certain seed-borne or soil-borne diseases. The establishment method such as direct sowing, dibbling, transplanting, or precision planting should be chosen according to the crop, soil, water supply and available equipment.

3. Build Soil Health and Apply Nutrients Wisely

Soil is a living resource that supports crop growth. If nutrients removed by successive harvests are not replaced appropriately, soil fertility and biological activity may decline over time. Integrated Nutrient Management (INM) aims to maintain a balanced supply of nutrients by combining mineral fertilizers with suitable organic sources such as farmyard manure, compost, green manure, crop residues and biofertilizers.

Soil testing helps identify nutrient needs and supports more informed fertilizer decisions. Recommendations should take account of the crop, test results, expected yield and local guidance. Organic materials and suitable cover crops can improve soil structure and water-holding capacity. Legumes may contribute nitrogen through biological fixation, although the contribution varies with crop growth, nodulation and management.

Micronutrients—including zinc, boron and iron—should be applied when a deficiency has been identified and a suitable corrective measure is recommended. Balanced nutrition is generally more useful than excessive fertilizer use; applying more than the crop needs does not guarantee a larger harvest.

4. Use Water Efficiently

Water supports germination, nutrient movement and uptake, photosynthesis and crop development. Too little water can restrict growth, while over-irrigation may waste water, cause waterlogging and affect crop performance.

Irrigation should be planned around the crop's growth stage, soil moisture, weather and available water supply. Drip systems can deliver water close to the root zone in suitable crops, while sprinkler systems may be appropriate in other crop and soil situations. In rice, alternate wetting and drying can reduce irrigation demand when field conditions and crop-stage requirements allow it and the method is managed correctly.

Useful water-saving measures include:

- Levelling fields where needed to improve irrigation uniformity.
- Applying mulch to limit evaporation and help suppress weeds.
- Collecting rainwater and using farm ponds where practical.
- Providing adequate drainage to prevent waterlogging.
- Using soil-moisture sensors or careful field observations to guide irrigation.

5. Combine Methods for Weed Control

Weeds compete with crops for light, space, moisture and nutrients and some can harbour crop pests or pathogens. If they are left uncontrolled during sensitive growth stages, crop yield may be reduced.

Integrated Weed Management (IWM) combines preventive, cultural, mechanical and chemical options. Depending on the crop and weed species, farmers may use crop rotation, timely sowing, appropriate plant spacing, mulching, stale seedbed methods, or mechanical weeding. Herbicides can be included when they are recommended for the crop, target weeds and application stage.

Any herbicide must be used according to its label, including the recommended rate, timing, protective measures and other safety directions. Repeated use of herbicides with the same mode of action can favour resistant weeds. Combining suitable methods can make weed management more sustainable.

6. Manage Pests and Diseases Through an Integrated Approach

Insect pests and diseases can damage both the amount and quality of harvested produce. Spraying pesticides on a routine schedule without checking the field may increase costs, harm useful organisms and contribute to pesticide resistance.

Integrated Pest Management (IPM) focuses on preventing problems where possible, monitoring crop health, supporting natural enemies and using chemical controls only when justified. Farmers can inspect fields regularly, choose resistant or tolerant varieties where available, rotate crops, maintain field hygiene and conserve beneficial organisms such as ladybird beetles and parasitoids.

Pheromone traps, light traps and other monitoring tools can be useful for particular pests when used appropriately. Recommended biological-control agents may also be included. If pesticide treatment is necessary, only registered products should be used in line with label directions and local recommendations.

7. Prepare for Climate Variability

Changes in rainfall, temperature and humidity can affect crop establishment, flowering, grain filling, water availability and pest activity. ICM can strengthen farm resilience by combining suitable varieties, diversified cropping patterns, conservation practices and decisions informed by weather forecasts.

Weather information can help farmers choose appropriate times for sowing, irrigation, fertilizer application and crop protection. Practices such as maintaining soil cover, reducing unnecessary soil disturbance where suitable, intercropping and rotating crops may help protect soil and spread risk. Short-duration varieties and contingency crops can be considered where local recommendations support their use.

8. Use Mechanization and Precision Tools

Equipment such as seed drills, planters, transplanters, mechanical weeders and harvesters can help complete operations on time and reduce some labour demands. Precision agriculture adds tools including GPS, sensors, drones, satellite imagery and digital advisories to support more targeted decisions.

9. Harvest at the Right Stage and Protect Produce After Harvest

Crop management continues beyond maturity. Harvesting at the appropriate stage helps preserve yield and quality. Depending on the crop, delayed harvesting can increase shattering, weather damage, pest attack, or other field losses.

Careful threshing, drying, cleaning, grading and storage help maintain produce quality. Seed retained for planting needs particular attention to purity, germination, moisture content and storage conditions. Farmers should use suitable storage structures, keep produce at an appropriate moisture level and inspect stocks regularly for insects, mould and damage.

Barriers to Adoption

Farmers may find it difficult to adopt ICM because of limited technical knowledge, labour shortages, the initial cost of some equipment, uneven access to quality inputs, or a lack of timely advice. Interpreting soil-test reports and using weather-based recommendations can also require training and support.

Field demonstrations, practical farmer training, accessible soil-testing services, farmer producer organisations, custom-hiring centres and stronger extension programmes can help overcome these barriers. Agricultural universities and research institutions can tailor recommendations to local crops, soils and climates. Cooperation among farmers may also improve access to machinery, reliable inputs, technical guidance and markets.

Conclusion

Integrated Crop Management provides a practical framework for making crop production more productive, resource-efficient and sustainable. By coordinating seed quality, soil care, balanced nutrition, water management, weed control, pest and disease management, climate adaptation, appropriate technology and post-harvest handling, farmers can make better use of the resources available to them.

Bringing Farm Practices Together for Better Yields and Sustainable Agriculture

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Volume: 06 Issue No: 10

MEALYBUGS: A GROWING THREAT TO VEGETABLE AND FRUIT CROPS

Article ID: AG-VO6-I10-63

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Introduction

Mealybugs are small, soft-bodied and highly destructive sap-sucking insect pests that attack a wide range of vegetable and fruit crops. The name "mealybug" is derived from the white, powdery, wax-like coating covering their body, which makes them appear like small tufts of cotton. They are generally found in groups on the undersides of leaves, at branch junctions, on tender shoots and around fruits.

India is an agriculture-dependent country, where vegetable and fruit production is an important source of income for farmers. However, increasing pest and disease incidence has become one of the major challenges in crop production. Various insect pests and diseases adversely affect crop yield and quality. Among these, mealybugs are important sap-sucking pests that have caused considerable economic losses in vegetable and fruit crops in recent years.

Mealybugs are not newly emerging insects; rather, they comprise a group of sap-sucking insects that have long been present in nature. Under favourable environmental conditions, their populations can increase rapidly and cause serious damage to crops.

Identification of Mealybugs

Correct identification of mealybugs is essential for their timely management. The insects are characterized by a white, waxy or powdery coating over their bodies, giving them a cotton-like appearance. They are commonly found in groups on the undersides of leaves, tender stems, branch junctions and around fruits.

Infested plants often show increased activity of ants. Ants are attracted to the honeydew secreted by mealybugs and, in turn, may protect them from their natural enemies.

Therefore, the presence of ants on plants can also serve as an indication of mealybug infestation.

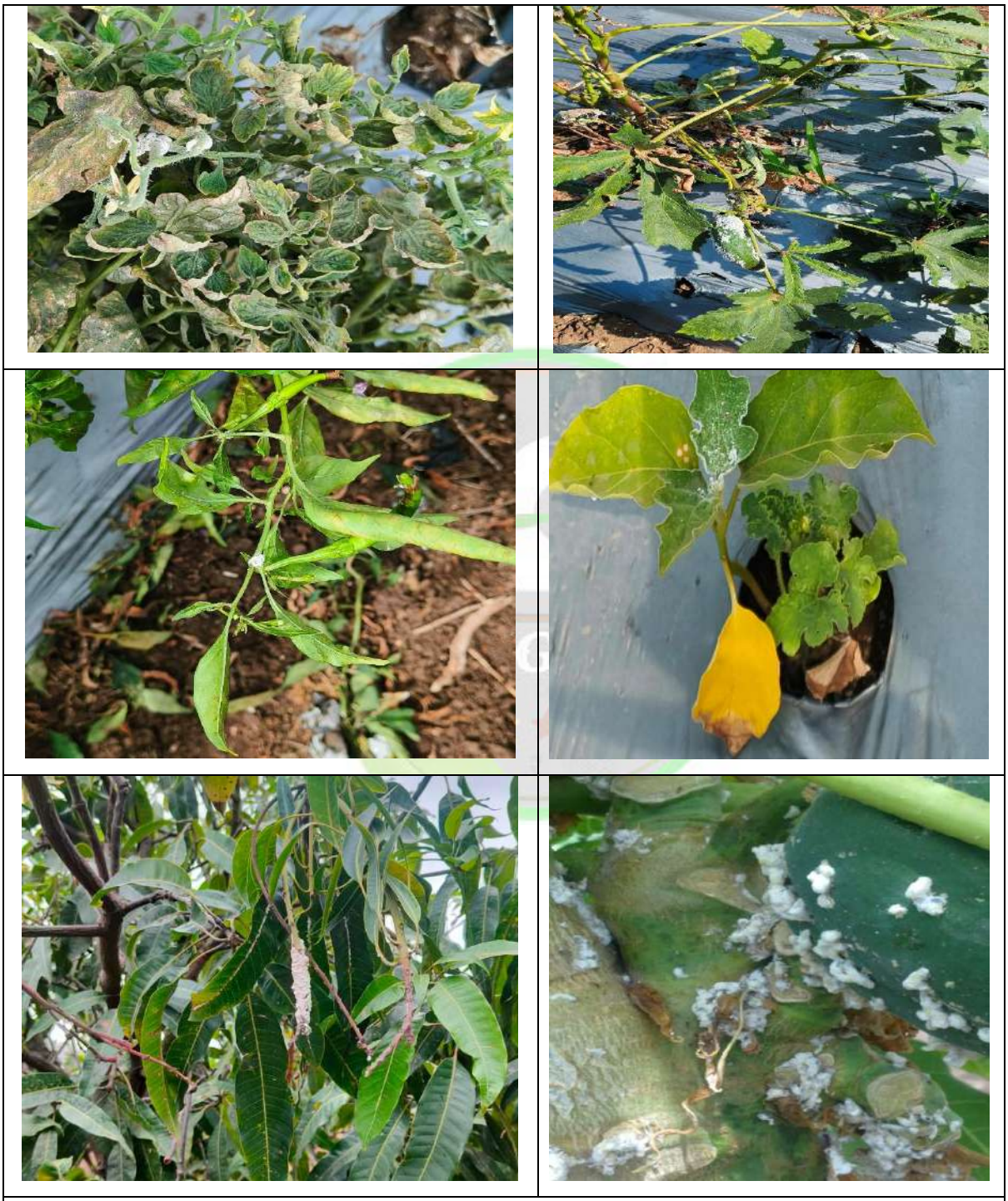


Fig 1. Mealybugs infestation in vegetable and fruit crops

Life Cycle of Mealybugs

The life cycle of mealybugs consists of the egg, nymph and adult stages. Female mealybugs lay a large number of eggs, from which nymphs emerge and disperse to different parts of the plant. The nymphs begin feeding by sucking plant sap and gradually develop into adults.

Mealybugs multiply rapidly under warm and relatively dry conditions. Several generations may occur within a year, allowing their populations to increase rapidly when favourable conditions prevail.

Major Mealybugs Found in India

Several species of mealybugs occur in India. Important ones include:

- Papaya mealybug
- Citrus mealybug
- Mango mealybug
- Cotton mealybug
- Root mealybug

Damage Caused by Mealybugs in Different Crops

1. Tomato

In tomato, mealybugs mainly infest leaves, tender stems and fruits. They suck plant sap, causing leaves to turn yellow and become distorted or curled. Continuous feeding weakens the plant and gradually reduces its growth.

Fruit development may also be affected, resulting in smaller fruits with reduced appearance and market quality. In severe infestations, premature fruit drop may occur. Consequently, crop productivity can be substantially reduced, with losses of about 30–40% reported under severe infestation.

2. Brinjal (Eggplant)

In brinjal, mealybugs are commonly found in groups on stems, leaves and fruits. Continuous sap feeding weakens the plant and affects the development of new shoots and branches.

Infested fruits may remain small or become distorted, thereby reducing their market value. Under severe infestation, plants may gradually dry up, and yield losses of approximately 35–50% may occur.

3. Okra

In okra, mealybugs are generally found on the undersides of leaves and other tender plant parts. They suck sap and weaken the plants. Infested leaves may curl and develop yellowing. Fruit development is adversely affected, and the pods may remain small, thin and poorly developed. Severe infestation can suppress plant growth and may result in approximately 20–30% reduction in yield.

4. Chilli

In chilli, mealybugs mainly attack flowers, tender shoots and leaves. Their feeding may result in flower and young fruit drop. Plant growth becomes stunted, while leaves may become curled and distorted.

As a result, both the quality and yield of chilli are affected. Severe infestations may cause 25–40% yield loss.

5. Papaya

Papaya mealybug is considered one of the most destructive mealybugs affecting papaya. It attacks leaves, stems, fruits and even the upper portions of the plant, often covering infested plant parts with a thick white, waxy coating.

Infested leaves turn yellow and may eventually dry up. Plant growth is severely affected, while fruits may remain small and may drop prematurely. Under severe infestation, the entire plant may dry up. In some areas, losses of 50–80% have been reported.

6. Grapes

Mealybug infestation in grapevines and fruit clusters can be particularly serious. The insects suck sap from fruits and tender shoots, adversely affecting the development of grape clusters.

The honeydew secreted by mealybugs promotes the growth of sooty mould, which blackens the fruit surface and reduces its appearance and market quality. This is particularly important in export-quality grapes, where even minor contamination can result in considerable economic losses. Under severe infestation, losses may reach 40–60%.

7. Pomegranate

In pomegranate, mealybugs may infest fruits, shoots and leaves. Infested fruits may develop poor external appearance and, in severe cases, may be prone to cracking. Fruit quality and sweetness may also be affected.

The development of new shoots and overall plant growth can be adversely affected under heavy infestation.

8. Mango

Mango mealybug is particularly damaging during the flowering period. It feeds on tender shoots and inflorescences, causing flowers to dry and adversely affecting fruit set.

The dropping of young fruits may increase, resulting in reduced fruit production and yield.

Major Factors Responsible for Mealybug Population Increase in India

The major factors favouring the multiplication and spread of mealybugs include:

- Warm and dry climatic conditions
- Imbalanced use of fertilizers
- Excessive weed growth
- Use of infested planting material
- Reduction in natural enemies
- Continuous cultivation of the same crop

How Does Integrated Pest Management Work Against Mealybugs?

Integrated Pest Management (IPM) involves the combined use of different pest management approaches rather than relying solely on chemical pesticides. The objective is to keep pest populations below economically damaging levels while minimizing adverse effects on the environment, soil and beneficial organisms.

IPM is particularly important for managing mealybugs because they multiply rapidly, often remain hidden in protected plant parts and may develop resistance to insecticides when chemicals are used repeatedly.

i. Use Healthy and Pest-Free Planting Material

Healthy, clean and pest-free seedlings or planting material should always be used. Mealybugs may enter the field through infested nursery plants.

Weeds should be regularly removed because they can serve as alternative hosts for mealybugs. Excessive application of nitrogenous fertilizers should also be avoided, as excessive vegetative growth and tender plant tissues can favour mealybug multiplication.

ii. Regular Monitoring

- Regular monitoring is one of the most important components of IPM. Plants should be inspected every 4–5 days, particularly the undersides of leaves, tender shoots, branch

- junctions and other soft plant parts.
- Early detection allows timely intervention before the pest population reaches damaging levels.

iii. Manual Removal

When infestation is low and localized, infested leaves, shoots, branches or severely affected plant parts should be manually removed and destroyed.

This simple practice can help prevent the pest from spreading to healthy parts of the plant.

iv. Conservation and Use of Natural Enemies

Natural enemies such as ladybird beetles and parasitoid wasps play an important role in naturally suppressing mealybug populations. Their conservation should therefore be an important component of mealybug management.

Unnecessary or indiscriminate pesticide applications should be avoided to protect these beneficial organisms.

v. Use of Neem-Based Products

Neem oil and neem-based products can interfere with the growth and reproduction of mealybugs. Neem-based products are relatively safer for many beneficial insects and therefore can form an important component of an IPM programme.

vi. Ant Management

Ants often protect mealybugs because they feed on the honeydew secreted by them. Therefore, management of ant populations is also important for effective mealybug control.

Reducing ant activity can expose mealybugs to their natural enemies and improve biological control.

vii. Monitoring with Sticky Traps

- Yellow sticky traps may be used as a supplementary monitoring tool for detecting the presence and movement of mealybugs and other insect pests at an early stage.
- However, sticky traps should be considered as part of an overall monitoring programme rather than as a stand-alone control measure.

viii. Chemical Control

- Chemical control should be considered only when the pest population reaches economically damaging levels and other management measures are insufficient.

- Their use should always be based on the crop, target pest, registered label recommendations and locally approved doses and application methods.
- Repeated use of the same insecticide or insecticide group should be avoided to minimize the risk of insecticide resistance.

Resistant Varieties and Research

- At present, completely mealybug-resistant varieties are limited in most crops. However, research institutions are working towards developing resistant or tolerant varieties, improving natural plant resistance and understanding resistance mechanisms at the molecular level.
- Conservation of natural enemies and development of biological control technologies are also being explored as important components of sustainable mealybug management.
- Future research should focus on identifying resistant or tolerant genotypes, understanding host–pest interactions, developing effective biological control agents and integrating these approaches into environmentally sustainable pest management programmes.

Conclusion

Mealybugs are important economic pests of vegetable and fruit crops and can directly affect crop yield, quality and farmers' income. Their populations may increase rapidly under favourable environmental conditions, particularly in warm and dry weather. Climate variability, indiscriminate fertilizer uses and certain agricultural practices may further favour their multiplication and spread.

Timely identification, regular monitoring and adoption of integrated pest management practices can significantly reduce mealybug damage. An integrated approach involving healthy planting material, weed management, manual removal, conservation of natural enemies, neem-based products, ant management, monitoring and need-based use of registered insecticides can provide more effective and sustainable control. By adopting scientific and balanced pest management practices, farmers can not only protect crop productivity and quality but also conserve beneficial organisms, reduce unnecessary pesticide use and contribute to environmentally sustainable agriculture.

Volume: 06 Issue No: 10

ENTOMOPATHOGENIC NEMATODES AS BIOLOGICAL CONTROL AGENTS: BIOLOGY, APPLICATIONS, CONSTRAINTS AND FUTURE PROSPECTS

Article ID: AG-VO6-I10-64

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Abstract

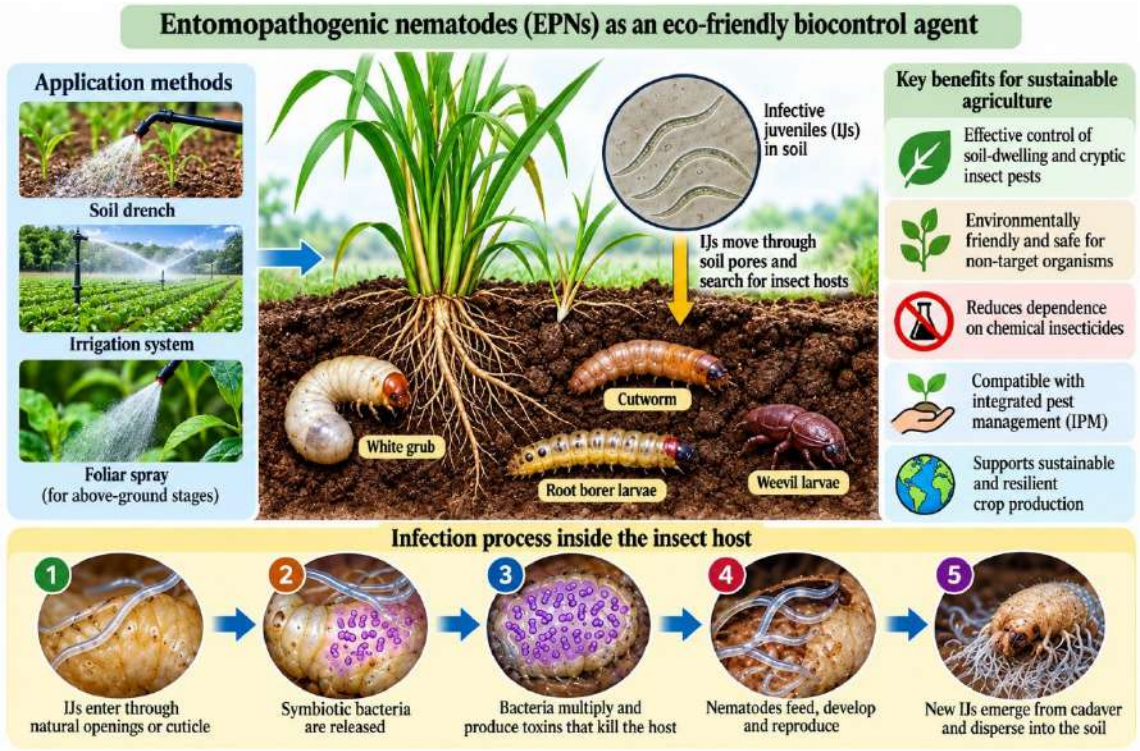
Heavy reliance on chemical insecticides has increased interest in biological alternatives. Entomopathogenic nematodes (EPNs) of the genera *Steinernema* and *Heterorhabditis* work with the bacteria *Xenorhabdus* and *Photorhabdus*, respectively, to kill insects, especially those living in soil. Their performance in the field depends on temperature, moisture, ultraviolet radiation, host susceptibility, strain, formulation and application method. Advances in mass production, formulation and strain characterization are addressing these limits. EPNs are best used as selected strains within integrated pest management.

Keywords: Entomopathogenic nematodes; biological control; IPM; biopesticides; sustainable agriculture.

Introduction

Synthetic insecticides have given farmers dependable crop protection, but their repeated use has brought resistance, residues, environmental contamination and harm to non-target organisms. This has encouraged the search for biological agents that fit into integrated pest management (IPM). Entomopathogenic nematodes (EPNs) are microscopic roundworms that hold an unusual position among them, because they work in partnership with insect-killing bacteria. The two genera that dominate research and commercial use are *Steinernema*, associated with the bacterium *Xenorhabdus*, and *Heterorhabditis*, associated with *Photorhabdus*. The nematode carries the bacteria into the insect, and the bacteria kill the host and create a nutritious

environment for nematode development. Unlike a conventional insecticide, EPNs actively search for hosts, penetrate them and multiply inside the dead insect. More than 100 *Steinernema* and



more than 20 *Heterorhabditis* species are now recognized, and new ones are still being described.

Fig. 1. Overview of EPNs as biocontrol agent

Biology and infection process

The EPN life cycle centres on the infective juvenile (IJ), a non-feeding stage that survives outside the host on stored reserves while it searches for an insect. Some species are active cruisers that move through the soil, others are ambushers that wait for a passing host, and some use an intermediate strategy. This behaviour determines which insects a species is likely to meet in the field. The IJ enters the insect through natural openings such as the mouth, anus or spiracles, and sometimes through thin cuticle. *Heterorhabditis* has an anterior tooth that helps it breach the body wall, whereas *Steinernema* relies mainly on natural openings. Inside the body cavity the nematode releases its bacterial partner, which multiplies rapidly and produces toxins and enzymes that suppress host defences and break down tissue. Death is therefore the result of a coordinated nematode–bacterium attack. The cadaver then becomes a food source in which the nematodes feed, mature and reproduce. When resources run low, a new generation of IJs

emerges and moves into the soil to find fresh hosts, so one treatment can pass from insect to insect.

Agricultural importance and target pests

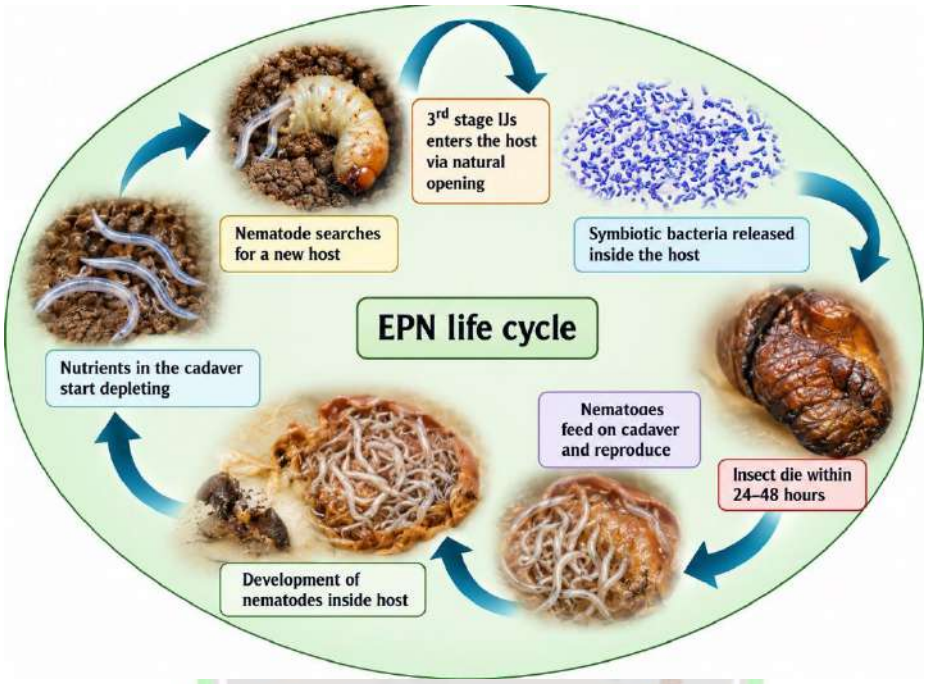


Fig.2. Developmental cycle of entomopathogenic nematodes within insect hosts

EPNs have been tested against insects in several groups, including beetles, moths and flies. Their greatest value lies against soil-dwelling or otherwise protected stages such as white grubs, cutworms, root feeders, weevils and borers. Soil gives IJs a protected environment and pore spaces through which to move, so they can reach pests in the root zone that foliar sprays miss. EPNs are not, however, effective against every insect. Host species, developmental stage, body size, immune response and behaviour all influence infection, so choosing the right strain for the target pest and production system is one of the most important decisions. EPNs also combine well with other IPM components, including cultural practices, resistant varieties, microbial agents, pheromone-based tools and compatible chemicals. The aim is to use them where their biology offers a real advantage, not to replace every insecticide.

From laboratory production to commercial application

Commercial use depends on producing large numbers of high-quality IJs. In vivo production infects a susceptible insect, usually the greater wax moth (*Galleria mellonella*), and

collects the IJs that emerge from the cadavers. It is simple and suits laboratory work, strain maintenance and small-scale production, but rearing large numbers of insects is labour intensive. In vitro production, using solid media or liquid fermentation, offers greater automation and scale. Large-scale culture, however, must still maintain the bacterial symbiosis, nematode infectivity and fitness. A nematode that multiplies well in the laboratory may still fail commercially if it tolerates stress poorly, stores badly or performs inconsistently in the field, so production must be planned together with formulation, storage and application.

Formulation and application

IJs must stay alive between production and application, and remain active after reaching the target habitat. EPNs are traditionally applied as water suspensions through sprayers, irrigation systems or soil drenches. For soil applications, moisture matters most, because IJs need a water film to move through soil pores. Dry soil restricts movement and speeds water loss, while waterlogged soil reduces oxygen. On plant surfaces the problem is greater, since ultraviolet radiation and rapid drying quickly kill IJs, so application timing, canopy conditions and formulation become critical. Recent research has therefore focused on protective gels, polymers and other carriers that shield IJs from stress. A strain that performs excellently in the laboratory may do much worse after exposure to sunlight, heat or drying in the field, which makes application technology a central link between EPN biology and practical pest management.

Why field performance is sometimes inconsistent

Field results often fall short of laboratory results because bioassays control temperature, moisture and host density, whereas fields change constantly. Each species or strain has a temperature range within which movement, host finding and infection are most effective. Soil moisture, texture and pore structure affect how far IJs can travel, and sunlight and drying matter when nematodes are exposed above ground. EPNs also meet microbes, predators, other nematodes and competing organisms in the soil, although some of these interactions are neutral or even complementary. Host susceptibility adds further variation, since different insects, and different stages of the same insect, respond differently to the same strain. Successful use therefore requires treating the nematode, host and environment as one connected system, rather than relying on laboratory pathogenicity alone.

Advantages and limitations

EPNs actively locate hosts, reproduce inside susceptible insects and work in habitats that conventional sprays cannot easily reach. Their bacterial partners kill the host quickly, and their ability to multiply in cadavers sets them apart from many other biological products. They also fit comfortably into IPM, which is especially valuable where the target insect spends part of its life in soil or another protected place. These advantages come with limits. EPNs are living organisms, so temperature extremes, low moisture, ultraviolet radiation, poor host susceptibility and badly timed application can all reduce control. Production, storage and formulation also affect product quality. Finally, only a small fraction of the known EPN diversity has entered commercial use, so much useful variation remains to be screened.

Where the field is heading

Future progress will come from understanding the nematode, its bacterial symbiont, the insect host and the environment as one system. Molecular tools are helping to resolve species and strain relationships and explain differences in virulence, host range, stress tolerance and symbiosis. Formulation research aims not just to keep nematodes alive in storage but to protect them during application and help them survive in the field, using gels, polymers and improved carriers. Native EPN populations may also gain importance, since strains adapted to local climate and soil can outperform introduced ones, and surveys of local diversity could provide strains suited to regional agriculture. The most useful approach is not to look for one universally effective nematode but to match the strain with the pest, crop, soil, climate, formulation and application method.

Conclusion

EPNs rest on a remarkable partnership between a host-seeking nematode and an insect-killing bacterium. Infective juveniles find insects, enter them and release their bacteria, which kill the host and allow the nematodes to multiply before a new generation emerges. The basic biology is well established, and better mass production, formulation and delivery are now easing the environmental limits that have held back field performance. EPNs should be seen not as simple replacements for chemical insecticides but as specialized tools, whose success depends on matching nematode, insect, crop and environment. Used carefully within an IPM programme, they offer a valuable addition to sustainable crop protection.

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Volume: 06 Issue No: 10

THE INCREDIBLE EGG: FROM FORMATION TO FUNCTIONAL FOOD

Article ID: AG-VO6-I10-65

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Introduction

The humble egg is one of nature's most remarkable packages of nutrition. Affordable, versatile and easy to prepare, it provides high-quality protein and several essential vitamins, minerals and other nutrients required for normal growth, tissue repair and body functions. Eggs are consumed worldwide in different forms, including boiled eggs, omelettes, scrambled eggs, egg curries and bakery products.Beyond their culinary importance, eggs represent an interesting intersection of reproductive biology, animal nutrition, food science and human health. An egg begins its journey in the reproductive system of a hen, develops through a highly organised biological process and emerges as a complete structure designed to support the development of an embryo when fertilisation occurs.Modern poultry science has further expanded the possibilities of egg production. Conventional table eggs, fertile eggs, eggs from indigenous poultry and designer eggs enriched with selected nutrients are now important subjects of research and consumer interest.Understanding how eggs form, what they contain, how they differ from other protein sources and how they should be selected and consumed can help consumers make informed dietary choices. At the same time, efficient backyard poultry production can support household nutrition, women's empowerment and sustainable rural livelihoods.

How Is an Egg Formed Inside a Hen?

Egg formation, or ovogenesis followed by egg development through the oviduct, is a fascinating physiological process. In the domestic hen, the reproductive system consists principally of the ovary and the oviduct. Although the embryo initially develops paired

reproductive structures, normally only the left ovary and left oviduct become functional in the adult hen.

The egg that appears simple on the outside is formed through several coordinated stages.

Stage 1: Development of the yolk in the ovary

The ovary contains numerous developing ova within follicles. As a hen approaches sexual maturity, selected follicles grow, accumulating yolk materials derived largely from nutrients synthesised and transported through the bloodstream. These materials include lipids, proteins, vitamins and other substances needed to nourish a developing embryo.As the follicle matures, the yolk becomes larger. Eventually, the mature yolk is released from the ovary through a process called ovulation.

Stage 2: Capture of the yolk by the infundibulum

Immediately after ovulation, the yolk is received by the infundibulum, the funnel-shaped first region of the oviduct. If sperm are present in the reproductive tract, fertilisation may occur in this region. If the hen has not mated with a rooster, the egg can still continue to develop and be laid normally, but it will be infertile.

Stage 3: Formation of the albumen or egg white

The yolk moves into the magnum, the longest region of the oviduct. Here, layers of albumen, commonly known as egg white, are deposited around it. Albumen contains water and proteins that provide protection and contribute to the nutritional requirements of the developing embryo.

Stage 4: Formation of the shell membranes

As the developing egg passes into the isthmus, two shell membranes are formed around the albumen and yolk. These membranes provide protective barriers and later help form the air cell at the broad end of the egg.

Stage 5: Formation of the hard eggshell

The egg then enters the uterus, also called the shell gland. Here, water and minerals are added, and calcium carbonate is deposited to form the hard shell. Shell pigmentation is also deposited in certain breeds during the final stages of shell formation. The shell contains numerous microscopic pores that allow the exchange of gases while helping protect the egg.

Stage 6: Cuticle deposition and laying

The outer cuticle, or bloom, is deposited near the end of shell formation. It helps protect

the shell surface. Finally, muscular contractions of the reproductive tract facilitate oviposition, meaning the laying of the completed egg.The entire process generally takes approximately 24–26 hours, although the timing varies with breed, age, environmental conditions and the hen's laying cycle. A hen may therefore lay an egg on most days during periods of active production, but uninterrupted daily laying should not be assumed.

The key message: Egg formation is a coordinated biological process in which the ovary produces the yolk and the oviduct adds the albumen, membranes and shell. The process also demonstrates why balanced feed, adequate calcium, appropriate lighting, good health and comfortable housing are important for successful egg production.

Inside an Egg: Understanding Its Major Components

A typical chicken egg contains four major structural components: the shell, shell membranes, albumen and yolk. Each performs a different function.

Egg component	Major characteristics and functions
Eggshell	Primarily calcium carbonate; provides mechanical protection and contains pores for gas exchange.
Shell membranes	Protective layers located beneath the shell; contribute to the formation of the air cell.
Albumen or egg white	Rich in water and proteins; provides physical protection and nutrients.
Yolk	Contains lipids, proteins, phospholipids, fat-soluble vitamins and other nutrients.
Chalazae	Twisted strands of albumen that help keep the yolk centrally positioned.
Germinal disc	A small region on the yolk surface associated with embryonic development; in a fertilised egg, the embryonic disc develops following fertilisation.

The relative proportions of these components vary according to egg size, breed, age and other factors. In a typical chicken egg, the albumen forms the largest proportion by weight, followed by the yolk and shell.The egg white is particularly useful as a concentrated protein source with very little fat. The yolk contributes much of the egg's fat, cholesterol and fat-soluble nutrients. Therefore, eating the whole egg provides a wider range of nutrients than consuming the white alone.

Nutritional Value of Eggs: More Than Protein

Eggs are recognised as nutrient-dense foods because they provide several nutrients in a relatively small serving. Their composition varies with egg size, the hen's diet and the production system.

High-quality protein: Egg proteins contain all nine essential amino acids that humans must obtain through food. The amino-acid profile and digestibility of egg protein make it useful for growth, maintenance and repair of body tissues.

Vitamin B12 and riboflavin: These vitamins support normal energy metabolism and other physiological processes. Vitamin B12 is particularly important for red blood cell formation and nervous system function.

Choline: Eggs are a useful dietary source of choline, a nutrient involved in cell membrane structure, neurotransmitter production and normal liver function.

Vitamin D and vitamin A: The yolk supplies these fat-soluble vitamins, although the amount varies with feed composition and other factors.

Selenium and other minerals: Eggs contribute selenium and smaller amounts of several other minerals needed for normal physiological functions.

Fats and phospholipids: The yolk contains fats and phospholipids, including lecithin, which contribute to cell membrane structure and nutrient transport.

Lutein and zeaxanthin: Egg yolks contain these carotenoids, which are associated with eye health. Their concentrations can be influenced by the hen's diet.

Eggs are not a complete substitute for a varied diet. They contain little dietary fibre and should be consumed alongside vegetables, fruits, whole grains, pulses, nuts and other suitable foods.

Egg Versus Meat and Other Protein Sources

Eggs, meat, fish, milk and pulses all contribute to dietary protein, but their nutritional profiles differ. The best choice depends on dietary preferences, affordability, availability, health requirements and the overall meal pattern.

Feature	Chicken egg	Chicken meat	Fish	Pulses and beans
Protein quality	High-quality complete protein	High-quality complete protein	High-quality complete protein	Protein quality varies; cereal-pulse combinations

				improve amino-acid balance
Main nutritional strengths	Protein, choline, vitamin B12, riboflavin and other nutrients	Protein, B vitamins, iron and zinc in varying amounts	Protein; some species provide omega-3 fatty acids and vitamin D	Protein, dietary fibre, folate and minerals
Dietary fibre	Absent	Absent	Absent	Present
Preparation	Boiling, poaching, omelette and other dishes	Cooking required; methods affect fat and energy content	Cooking required; nutrient profile varies by species	Soaking and thorough cooking may improve digestibility
Cost and convenience	Often convenient and relatively affordable	Varies by cut and local market	Varies substantially by species and location	Often economical and suitable for plant-based diets

Eggs are convenient because they can be prepared quickly and require little processing at home. Meat and fish may provide nutrients that are present in smaller amounts in eggs, while pulses offer dietary fibre that animal-source foods do not provide.No single food is universally superior. A balanced diet can include eggs, pulses, fish, meat or dairy according to an individual's preferences and nutritional needs. Vegetarian diets can also provide adequate protein when a variety of protein-rich plant foods are consumed in appropriate quantities.

Table Eggs and Fertile Eggs: What Is the Difference?

One of the most common misconceptions among consumers is that a fertile egg is automatically more nutritious than an ordinary table egg. Fertility refers to reproductive potential, not necessarily nutritional superiority.

A **table egg** is an egg produced for human consumption. Commercial laying hens generally produce table eggs without the presence of roosters. These eggs are normally infertile, but they can still be nutritious.

A **fertile egg** is produced when fertilisation occurs following mating or the use of appropriate breeding methods. Under suitable incubation conditions, a fertile egg may develop into an embryo and eventually hatch.

Feature	**Ordinary table egg**	**Fertile egg**
Fertilisation	Usually unfertilised	Fertilised
Rooster required in production flock	No	Yes, for natural mating
Intended use	Human consumption	Often incubation and hatching; may also be consumed
Embryonic development	Does not develop into a chick	Can develop when incubated under suitable conditions
Nutritional value	Nutritious source of protein and other nutrients	Broadly similar nutritional value before substantial embryonic development
Appearance	Usually indistinguishable externally from a fertile egg	Usually indistinguishable externally before development
Food safety	Requires hygienic handling and proper cooking	Also requires hygienic handling and proper cooking

Fertilised eggs do not automatically contain more protein or provide a proven general nutritional advantage over infertile eggs. The presence of a rooster does not itself make an egg nutritionally superior.When fertile eggs are intended for hatching, they must be collected, handled and incubated under suitable conditions. Eggs intended for consumption should not be assumed safe merely because they are fertile or obtained from backyard poultry.



What Are Designer Eggs?

Designer eggs, also known as nutrient-enriched or functional eggs, are eggs produced by modifying the hen's diet so that the finished egg contains increased quantities of selected nutrients.The principle is straightforward: certain nutrients consumed by the hen can be metabolised and deposited in the developing egg, particularly in the yolk. By carefully formulating poultry feed, researchers and producers can influence the nutrient profile of the eggs.Designer eggs are an active area of poultry nutrition research because they may help deliver specific nutrients through a familiar food.

Common approaches to designer egg production include:

Omega-3-enriched eggs: Feed ingredients such as flaxseed or linseed, selected marine oils and suitable microalgae can increase the omega-3 fatty-acid content of eggs. The extent of enrichment depends on the source, inclusion level, feed formulation and production conditions.

Vitamin E-enriched eggs: Appropriate dietary supplementation can increase vitamin E deposition in the yolk. The amount must be carefully controlled to meet nutritional and regulatory requirements.

Selenium-enriched eggs: Suitable selenium sources can be included in poultry diets to increase selenium content in eggs. Since selenium has a relatively narrow range between nutritional adequacy and excessive intake, supplementation requires careful formulation and quality control.

Carotenoid-enriched eggs: Feed ingredients containing carotenoids, including selected plant materials and microalgae, can influence yolk pigmentation and the concentration of particular carotenoids.

Combined nutrient-enriched eggs: Some research explores combinations of omega-3 fatty acids, vitamin E, selenium and carotenoids to produce eggs with multiple nutritional modifications.

How are designer eggs produced?

1. **Selection of the target nutrient:** The producer identifies the nutrient to be enriched, such as omega-3 fatty acids, vitamin E or selenium.
2. **Feed formulation:** A poultry nutritionist selects an appropriate feed ingredient and determines a safe inclusion level.
3. **Feeding and production:** Hens receive the formulated diet under suitable management conditions.

4. **Nutrient analysis:** Representative eggs are tested using appropriate analytical methods to determine the actual nutrient concentration.
5. **Quality assurance:** Production consistency, feed safety, egg quality and applicable labelling requirements are evaluated before making nutrition claims.

Designer eggs are not necessarily genetically modified eggs. In many established approaches, enrichment is achieved through feed formulation rather than genetic modification.However, an egg should not be marketed as omega-3-enriched, selenium-enriched or otherwise nutrient-enhanced solely because a particular ingredient was included in the feed. The final nutrient content should be demonstrated through appropriate analysis, and any health-related claims must be scientifically justified and compliant with applicable regulations.

Can designer eggs replace medicines or supplements? No. Nutrient-enriched eggs may contribute to dietary intake, but they should not be presented as treatments for diseases or substitutes for prescribed medication. Their value depends on the nutrient content, serving size, overall diet and individual nutritional needs.

10. Backyard Poultry: Linking Egg Nutrition with Rural Livelihoods

Eggs have significance beyond individual nutrition. Backyard poultry can provide households with a regular source of eggs and, where appropriate, additional income from the sale of surplus produce.For small and marginal farmers, women's self-help groups and rural households, indigenous and improved backyard poultry systems can offer an accessible livestock-based livelihood activity. However, success depends on sound management rather than breed selection alone.

Important practices include:

- Selecting suitable breeds or strains according to local climate, management capacity and market demand.
- Providing balanced feed and clean drinking water.
- Maintaining adequate housing, ventilation, nesting areas and protection from predators.
- Following appropriate vaccination and disease-prevention programmes with veterinary guidance.
- Collecting eggs regularly and handling them hygienically.
- Keeping poultry housing and feeding areas clean.

- Seeking veterinary assistance when birds show signs of illness or egg production declines.

Extension centres, veterinary institutions and agricultural organisations can support farmers through training in scientific poultry management, feed preparation, disease prevention, egg handling and marketing.For women-led poultry enterprises, regular egg production can improve household access to animal-source foods while creating opportunities for small-scale entrepreneurship. The nutritional and economic benefits are strongest when poultry health, feed availability, market access and household food needs are considered together.

Egg Safety: From Farm to Kitchen

An egg may be nutritious, but food safety must never be overlooked. Eggs can become contaminated during production, collection, transport, storage or preparation. Some pathogens, including *Salmonella*, may be present without obvious changes in the egg's appearance or smell. Consumers can reduce risks by following a few practical precautions:

1. Buy eggs with clean, intact shells from reliable suppliers.
2. Avoid cracked eggs and discard eggs that show clear signs of spoilage.
3. Store eggs according to local food-safety guidance and the supplier's instructions. Where refrigeration is used, maintain a consistent cold temperature.
4. Avoid unnecessary washing of eggs at home, as washing can damage the protective surface layer or introduce contamination through shell pores.
5. Cook eggs thoroughly, ensuring that both the white and yolk are set.
6. Wash hands, utensils and work surfaces after handling raw eggs.
7. Do not leave cooked egg dishes at room temperature for prolonged periods.
8. Take extra care when serving eggs to young children, older adults, pregnant people and individuals with weakened immune systems.

Raw or undercooked eggs carry a greater foodborne-illness risk than thoroughly cooked eggs. Clean appearance alone cannot guarantee safety.

12. Common Myths About Eggs: Facts to Remember

Myth 1: Brown eggs are always more nutritious than white eggs.

Fact: Shell colour is mainly related to the hen's breed. It does not independently establish nutritional superiority.

Myth 2: Fertile eggs are always healthier than infertile eggs.

Fact: Fertility refers to the potential for embryonic development. Fertile eggs do not automatically have a general nutritional advantage over ordinary table eggs.

Myth 3: The yolk should always be discarded.

Fact: The yolk supplies important nutrients, including choline and fat-soluble vitamins. Whether whole eggs or egg whites are more suitable depends on individual dietary needs.

Myth 4: A darker yolk proves that the egg is more nutritious.

Fact: Yolk colour is influenced by feed pigments and does not reliably indicate the overall nutrient content.

Myth 5: Eggs are suitable only for bodybuilders.

Fact: Eggs can be included in varied diets for people with different nutritional needs, subject to individual circumstances.

Myth 6: Every person should eat the same number of eggs daily.

Fact: Egg intake should be considered within the whole diet, age, health status, food preferences and energy requirements. No single quantity suits everyone.

Myth 7: Designer eggs cure diseases.

Fact: Nutrient-enriched eggs can contribute selected nutrients to the diet, but they are foods, not medicines. Disease-treatment claims require appropriate evidence.

The Future of Egg Production

The future of egg production will depend on combining animal welfare, scientific nutrition, food safety, efficient resource use and consumer confidence.Research opportunities include developing affordable nutrient-enriched eggs, evaluating indigenous poultry under different feeding systems, improving shell quality, reducing feed costs, exploring locally available feed resources and strengthening smallholder egg marketing.Designer eggs may create new opportunities for value addition, but they require reliable nutrient analysis, consistent production, clear labelling and evidence-based communication. Equally important is ensuring that conventional eggs remain affordable and accessible to households.For rural communities, improving backyard poultry productivity and reducing bird mortality may deliver immediate benefits even without specialised enrichment technologies. Better feed, disease prevention, housing and market access can improve both household nutrition and farmer income.

Conclusion

An egg is much more than a common breakfast food. It is the result of a carefully coordinated biological process and a valuable source of high-quality protein and essential nutrients. From the formation of the yolk and albumen to the deposition of the shell, egg development demonstrates the remarkable efficiency of avian reproduction.Understanding the differences between table and fertile eggs, interpreting ICMR–NIN dietary guidance correctly, recognising the influence of breed and feed on egg characteristics, and exploring designer eggs can help consumers make informed choices.At the same time, scientific backyard poultry production can support food security, women's entrepreneurship and rural livelihoods. The way forward is not to promote eggs through exaggerated claims, but to combine sound science, safe production, balanced nutrition and accessible extension services.

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Volume: 06 Issue No: 10

PROPER PLANNING AND RECORD-KEEPING ARE MUST FOR BETTER FARM RETURNS

Article ID: AG-VO6-I10-66

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Introduction

To be able to compete in the national and international market there is need to reduce cost of cultivation as well as to improve the quality of produce which is possible only through proper farm planning. Farm planning becomes more important as the farmer has to face emerging challenges of globalization, depletion of under-ground water table, decline in influx of migrants, increasing cost of production, etc. Various surveys revealed that there is a lack of proper planning at farmers' level. Proper planning must have provisions for proper use and conservation of natural resources, judicious use of agro-chemicals and increasing net income from the farm. Domestic needs of farming family in terms of vegetables, pulses, oil seeds, fruits, etc. should also be kept in view so as to have a least dependence on market. In brief, farm-planning is an act of proper analysis from all possible angles about the activity/enterprise to be started and to make it a success.

Farm-planning depends upon

- Selection of crops to be grown and concerned subsidiary occupations to be started.
- Area to be allocated under each crop and the size/volume of the selected enterprise.
- Quantity of inputs needed such as seed, fertilizer, pesticides, labor, etc.
- Source and time of procuring inputs.
- Way to dispose of the farm produce. Whether to store the harvested produce or to sell it immediately after harvest?
- Marketing of the produce at the right time and right market place.
- Price volatilization of commodities during the year/season.

Successful farm planning needs

- Complete knowledge of recommendations for all the crops which can be acquired by reading farm literature, through discussions with agricultural experts, through TV, Radio and internet programs, by attending seminars and farmers' training camps, etc.
- Knowledge about soil type and fertility status of the soil.
- Knowledge about the quantity and quality of irrigation water available at the farm is also very important as under-ground water of some of the districts of the state is brackish and due attention must be given while selecting the crops to be grown under such situations.
- Keep in mind the available scarce resources such as land, labor, FYM, animals, machinery, irrigation water, capital, etc. to decide the possibilities about the quantum of area to be put under different crops/enterprises. Care should be taken to include rented-in and rented-out resources.
- Preparation of different improved alternative farm plans while keeping in view the weaknesses of the existing plan, available resources, profitability of different crops and possible risks (which may be due to price fluctuations or decline in yield). These plans can be compared on the basis of net returns and the plan providing higher net returns can be accepted for implementation. There should be a scope for making changes (which may be required due to adverse weather or changes in prices) in the accepted farm plan.
- Assessment about the required inputs like seed, fertilizer, pesticide, capital, labor, machinery, etc. for the accepted farm plan should be made in advance. Quantity of inputs and place from where to procure these inputs must also be taken care of.
- Proper maintenance of farm records for the preparation of optimum farm plan. This enables the farmer to have accurate information about the costs and returns from different crops/enterprises. Farmer can give priority to the activity providing higher net returns. The activity producing lower net returns can be reduced or eliminated from the plan to make farming more economical. Maintenance of farm records enables the farmer to assess whether added costs have increased the returns or not and if increased, then to what extent? Farming remains economical so long as the added returns are higher than the added costs which are the base for the expansion of farming/enterprise.

- National and international marketing structure, import and export possibilities also needed to be kept in view.

Planning for horticulture

Planning for enterprises other than crops must be there to adjust the work force spared due to decreasing size of the holdings and continuous mechanization in agriculture. In horticulture, both vegetable and fruit cultivation can be added in the agriculture plan. Vegetable crops are of short duration, risky but highly profitable whereas fruit cultivation is long duration and less risky enterprise. The following points must be kept in mind while planning the establishment of fruits orchards as it requires long run decisions to make it a sustainable business.

- Locality survey to assess the already existing area and the possible markets for horticulture crops is must for a good start.
- Quality seedling, soil, water and labour availability including family labour is perquisite for this enterprise.
- To face the volatile prices in vegetables and fruits, their processing and value addition must also be planned so as to sustain this business over long time. For this purpose, continuous interaction with the agri-experts of Punjab Agricultural University and Department of Horticulture, Punjab is necessary.
- To increase the farmer's share in net returns, the concept of self-marketing in both fruits and vegetables must be added in the farm planning.

Benefits of farm planning

- Comparison of different crop rotations and subsidiary occupations can be easily made which is pre-requisite for proper planning.
- Beneficial to assess the gap between potential yield and yield realized by the farmer which enables him to find remedial measures. Profitability of subsidiary occupations can be worked out and planning can be modified to reduce the losses or to improve the profits.
- Farmer can assess the amount of capital required and the loan to be taken. Farmer can implement the plan by taking loan well in advance and from the right institute of his choice.

- Weaknesses in the existing farm plan can be identified which is very useful in preparing improved plan.
- Useful for government for making various policies.
- Useful for providing feed back to the research system.

Conclusion

The farmer needs to prepare the plan well in advance to take full advantage of the existing resources. In view of the swift changes in technology, farming has not remained an easy task. So, success in farming lies on proper farm planning. This will not only help in optimum utilization of the limited resources but will improve the income level and living standard of the farmer also.

Volume: 06 Issue No: 10

VALUE ADDITION IN FLOWER CROPS FOR IMPROVED LIVELIHOOD

Article ID: AG-VO6-I10-67

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Introduction

Value addition is used because of its perishable nature where flowers cannot be stored for long time and during flowering season, farmers may not get good price due to glut in the market. In this situation, value addition is a best alternative to increase the farm income.

Value addition of flowers is the process of adding value to the flower or ornamental crops either through form, space or time utility. This may be a perfect choice for women entrepreneurship. Because unlike other agricultural or horticultural commodities, flowers are ultimately expounded for beautifying and enhancing the aesthetic sense of environment. Women are naturally connected more with flowers by using them for worship, hair adornment, etc. So, this natural bond could be manipulated to craft admirable and innovative products out of flowers. Moreover, it does not need wider scientific and research knowledge and is entirely oriented on skill and creativity. Hence, value addition could significantly aid in empowering women by tapping their hidden potential.

Objectives of value addition

- To improve quality.
- To enhance selling.
- To gain higher profit.
- To reduce post harvest loss.
- Improve employment generation.
- Increase in export.

Benefits of Value addition

- Value addition utilizes the excess flowers in season.

- It reduces the floral waste.
- It stabilizes the rate of flowers in the market.
- It stabilizes the farm income.
- It creates novelty and variety of floral products.
- It provides more employment to farming community.
- It provides the space for entrepreneurship development.
- It spreads the availability of flowers throughout the year.

Value Added Products

Fresh flowers, dry flowers and even the floral waste can be utilized for value addition in an enterprise level. Nowadays, there is an increasing demand of floral arrangements in hotels, restaurants, IT companies and multi-national companies to increase employees‟ work efficiency by improving the working environment. Thus, women self help groups (WSHG) and women co-operatives can themselves indulge in such floral designing and arrangement activities. Loose flower crafts too have great requirement especially during festivals and weddings. Some of the well known loose flower crafts in south India are thodutha maalai, kortha maalai, veni, ghajra, bridal crowns and jadai. Further, women can be trained to extract essential oils as Government of India is encouraging women with several schemes and subsidies for setting up their own enterprises.

The demand for dry flowers is increasing at an impressive rate of 8-10 % and therefore there is a great scope for women entrepreneurs. Dry flower articles like dry flower bouquets, floral cards, wall hangings, sceneries, photo frames, wreathes, pomander, night lamps, backdrops, potpourris, dried flower candles, herbal soaps are also popularising in the market. Also, making floral ornaments such as ear rings, pendants and key chains made of dried, special flowers like autumn leaves, roses, dandelions, bougainvillea, jasmine, Lantana camara and orchids using heated resin or natural edible wax could pick up rapidly as the consumers always desire for novel products.

Edible flower products like pickles from dried magnolia & liliums, sugared candies from pressed flowers of pansy, jams and jellies from hibiscus, rose & lotus, sweets, chocolates, cookies and cakes from dried petals of marigold, rose & carnation and rose gulkhand could be the great platform for women entrepreneurship as these are simple to execute and the women has in-built talent to plan amazing food products.

The commercial potential of flowers can be significantly enhanced through value addition and processing, particularly in the nutraceutical and dry flower industries. Flowers are abundant in bioactive substances, vitamins and antioxidants, making them valuable for the nutraceutical sector, which is increasingly recognizing their health benefits (Nagajyothi and Pratheeksha, 2023). Additionally, the dried flower market, which constitutes about 15% of the global floriculture business, has gained traction due to rising demand for eco-friendly products,

Conclusion

Value addition in flower crops holds immense potential to transform the floriculture industry from a seasonal, perishable-based sector to a robust, diversified, and sustainable economic activity. Through innovative processing, efficient waste utilization, and market-focused product development, farmers and entrepreneurs can unlock new avenues for income and employment. Crafting in floriculture through dry flower making, floral decor, bouquet making, dry flower frames & articles and potpourris by using ornamental plants is considered as an ideal venture in the recent past for livelihood and women empowerment.

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Volume: 06 Issue No: 10

STRENGTHENING VILLAGE-LEVEL INSTITUTIONS FOR EFFECTIVE CLIMATE RISK MANAGEMENT

Article ID: AG-VO6-I10-68

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Introduction

Climate change has emerged as one of the major challenges facing Indian agriculture, particularly in rainfed regions where crop production depends heavily on the timing, distribution and amount of rainfall. Erratic monsoons, prolonged dry spells, rising temperatures, recurrent droughts and extreme weather events have increased uncertainty in agricultural production and threatened the livelihoods of small and marginal farmers. These challenges are especially serious in semi-arid regions, where limited irrigation facilities, degraded natural resources and inadequate access to agricultural services make farming highly vulnerable to climatic shocks.

Although improved crop varieties, weather forecasts, crop insurance and climate-smart technologies can reduce agricultural risks, their effectiveness depends largely on how efficiently they reach farmers and how effectively communities use them. Individual farmers often lack the financial resources, technical knowledge and institutional support required to manage climate risks independently. Therefore, strengthening village-level institutions is essential for promoting collective action, improving access to resources and building resilient agricultural communities.

Village-level institutions provide an important link between farmers, agricultural universities, Krishi Vigyan Kendras (KVKs), government departments, financial institutions and markets. By facilitating community participation, sharing information, mobilising resources and coordinating adaptation measures, these institutions can transform climate risk management from an individual responsibility into a collective village-level effort.

Understanding village-level institutions

Village-level institutions are formal or informal organisations that bring rural people together to address common agricultural, economic, social and environmental challenges. They facilitate collective decision-making, resource management, knowledge exchange and the implementation of development programmes.

In climate risk management, these institutions help identify local vulnerabilities, assess available resources, prepare contingency plans and implement suitable adaptation strategies. Their effectiveness depends on community participation, leadership, financial resources, technical knowledge, transparent governance and coordination with supporting organisations.

Important village-level institutions include:

- **Village Climate Risk Management Committees (VCRMCs):** Coordinate village-level climate risk assessment, preparedness, adaptation planning and response activities.
- **Self-Help Groups (SHGs) and women's groups:** Support savings, access to credit, livelihood diversification, nutrition security and women's participation in climate-related decisions.
- **Farmer Producer Organisations (FPOs) and cooperatives:** Facilitate collective input procurement, aggregation, marketing, value addition and access to institutional services.
- **Custom Hiring Centres (CHCs):** Provide access to agricultural machinery at affordable rental rates, helping farmers complete critical operations within short sowing windows.
- **Community seed banks:** Preserve, multiply and distribute locally suitable and climate-resilient seed varieties.
- **Fodder banks:** Store and distribute fodder to support livestock during droughts and periods of feed scarcity.
- **Water User Associations and other natural resource management groups:** Promote efficient water use, watershed management, soil conservation and maintenance of common resources.

Each institution performs a distinct function, but coordination among them creates a stronger and more comprehensive system for managing climate risks.

Why are village-level institutions important?

1. Identifying local climate risks

Climate risks vary from village to village depending on rainfall patterns, soil

characteristics, cropping systems, water availability and livelihood activities. Village institutions can bring together farmers, extension workers and local leaders to identify major risks, vulnerable households and available resources.

Participatory village meetings, seasonal calendars, historical rainfall records, resource mapping and farmer experiences can help communities understand the timing and nature of climate-related threats. Based on this information, villages can identify priority interventions, such as drought-tolerant crops, contingency sowing, soil moisture conservation, fodder storage and water harvesting.



Institutions for Effective Climate Risk Management at Village Level

2. Improving access to climate information

Timely and understandable weather information is essential for agricultural decision-making. However, farmers may not always receive forecasts in a suitable language or know how to translate them into farm-level actions. Village institutions can work with KVKs, agricultural universities, agricultural extension officers and weather advisory services to disseminate local-language information on rainfall forecasts, sowing windows, pest and disease risks, irrigation scheduling and contingency crop planning. Information can be shared through village meetings,

mobile messages, WhatsApp groups, notice boards, farmer field schools and community demonstrations. Local institutions can also communicate farmers' problems to technical experts and obtain timely advice.

3. Mobilising financial and material resources

Climate adaptation often requires investments in seed, machinery, irrigation, livestock feed, storage facilities and soil and water conservation. Limited financial resources can prevent vulnerable farmers from adopting suitable practices. Village institutions can help farmers access eligible government schemes, agricultural credit, crop insurance, subsidies and development programmes. SHGs, cooperatives and FPOs can strengthen collective financial capacity, while community institutions can mobilise locally available resources for priority activities. Transparent financial management, proper record-keeping and clear rules for using common funds are essential to maintain trust and ensure that benefits reach the intended households.

4. Ensuring timely access to agricultural inputs and machinery

In rainfed agriculture, even a short delay in sowing may reduce crop establishment and yield potential. Custom Hiring Centres can help small and marginal farmers access tractors, seed drills, weeders and other machinery without purchasing expensive equipment individually. Similarly, community seed banks can maintain adequate stocks of suitable varieties and distribute seeds when rainfall conditions favour sowing or resowing. Coordination between seed banks, CHCs and farmer groups can improve preparedness before the monsoon and reduce delays during critical agricultural operations.

5. Protecting livestock during drought

Livestock provides income, nutrition, savings and livelihood security to many rainfed farming households. During droughts, fodder shortages and rising feed costs may force farmers to sell animals under distress. Fodder banks can reduce this vulnerability by storing dry fodder, crop residues and other locally suitable feed resources during periods of availability. Where technically and economically feasible, silage preparation and fodder conservation can extend feed availability into dry periods. Village institutions can coordinate fodder procurement, storage, transport and fair distribution, while linking livestock farmers with veterinary services, cooperatives and relevant government programmes.

6. Strengthening social inclusion and collective action

Climate risks do not affect all households equally. Small and marginal farmers, tenant

cultivators, agricultural labourers, women farmers and livestock-dependent households may face different constraints in accessing information, finance and support services. Village institutions should ensure that these groups participate meaningfully in planning and decision-making. Women's SHGs, farmer groups and community-based organisations can help identify the specific needs of vulnerable households and improve access to information, credit, training and livelihood opportunities. Inclusive institutions also promote trust, mutual support and collective responsibility during climate-related emergencies.

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Volume: 06 Issue No: 10

ROLE AND RESPONSIBILITIES OF PET OWNERS IN THE PREVENTION AND CONTROL OF RABIES

Article ID: AG-VO6-I10-69

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Introduction

Rabies is a vaccine-preventable, zoonotic viral disease that affects the central nervous system and is almost fatal once clinical signs develop. Despite the availability of effective animal and human vaccines, rabies remains an important public health problem in India. Out of the total 59,000 rabies death worldwide 20,000 rabies deaths each year occur in India and it is the highest for any country. The disease mainly affects children and socially and economically vulnerable populations who have limited access to timely healthcare and post-exposure prophylaxis. Dogs are the principal reservoir and source of human exposure in many endemic areas. Hence, prevention at the animal level is one of the most effective ways to control the transmission to humans. The WHO, Food and Agriculture Organization (FAO), World Organisation for Animal Health (WOAH), and Global Alliance for Rabies Control (GARC) have adopted a One Health strategy aimed at ending human deaths from dog-mediated rabies by 2030.

This strategy recognizes that rabies control requires coordinated action involving animal health, human health, environmental management, surveillance, vaccination, responsible animal ownership, and community participation. Within this framework, pet owners have an important role. Responsible ownership is not limited to providing food, shelter, and routine veterinary care; it also includes maintaining vaccination, preventing dogs from free roaming and unwanted interactions, reducing the risk of animal bites, preventing uncontrolled breeding, responding appropriately to suspected exposures, and cooperating with veterinary and public health authorities.

Maintaining Regular Rabies Vaccination of Pets

The most important responsibility of a pet owner in rabies prevention is ensuring that dogs and other susceptible pets receive rabies vaccination according to the schedule recommended by a veterinarian and local regulations. Vaccination protects the individual animal and substantially reduces the probability of infection and transmission from animals to human beings. Owners should maintain an up-to-date vaccination record and ensure that booster vaccinations are administered at the recommended intervals. Vaccination should not be viewed as a one-time intervention. The importance of vaccination extends beyond the individual pet. Vaccination is a population-level public health intervention because high vaccination coverage reduces transmission within dog populations and consequently reduces human exposure. Evidence from modelling and systematic reviews indicates that achieving approximately 70% herd immunity in dog populations is a critical benchmark for interrupting dog-mediated transmission in endemic areas. Pet owners should therefore participate in government or community dog-vaccination programmes whenever appropriate and encourage other owners to vaccinate their animals.

Preventing Pets from Roaming Freely

Pet owners should prevent dogs from roaming unsupervised. Pets should be kept within secure premises or appropriately restrained during outdoor activity like walking. Dogs should ideally be walked on a leash and should not be allowed to interact freely with unknown dogs or wild animals. In dogs, free roaming creates several opportunities for rabies exposure. An unrestrained pet may encounter an infected dog, bat, fox, jackal, or other mammal, get involved in a fight, or be bitten without the owner immediately noticing the wound. Uncontrolled roaming also increases the possibility that a pet will bite another animal or person. Behavioural management, socialization, recognition of fearful or aggressive behaviour, and avoidance of situations that provoke defensive responses are important components of responsible pet ownership. Pet owners should also avoid leaving food waste, garbage, or pet food exposed outdoors because these can attract free-roaming animals and wildlife. Secure waste management can therefore contribute indirectly to reducing animal-to-animal and animal-to-human contact.

Preventing Unwanted Breeding and Supporting Population Management

Uncontrolled breeding leads to increasing dog populations and can tamper the efforts to achieve sustained rabies vaccination coverage. Pet owners have a responsibility to prevent

unwanted litters and should be convinced to adopt sterilization on animals when breeding is not intended. Owners should never abandon unwanted puppies or adult dogs. Abandonment may contribute to the growth of free-roaming dog populations and increases the number of animals with uncertain vaccination status. Instead, owners should seek appropriate options through veterinary services, animal welfare organizations, shelters, or local authorities. Pet owners can cooperate with municipal authorities and animal welfare programmes involved in sterilization, vaccination, identification, and responsible dog population management. Mass vaccination and sustained, dog population-management measures are central to rabies control.

Preventing Contact with Wild and Unknown Animals

Pet owners should prevent their animals from interacting with wildlife and unfamiliar domestic animals. Wild mammals can carry rabies, and unusual behaviour like unexplained aggression, abnormal vocalization, disorientation, paralysis, or loss of normal fear of humans are considered as potential warning sign for rabies. Owners should never encourage pets to chase, capture, or fight wild animals. Special caution is warranted around bats, foxes, jackals, mongooses, and other mammals that may potentially transmit rabies in endemic regions. A suspected rabid animal should not be handled directly. Instead, the owner should report the animal to an appropriate veterinary, municipal, wildlife, or public health authority. Early reporting can permit can reduce the risk and hence protect humans and other animals. Pet owners should also teach children not to approach animals that are unfamiliar, sick, injured, behaving abnormally, or feeding young. Children represent an important vulnerable group in rabies-endemic settings, making education within the household an essential component of prevention. WHO reports that children account for a substantial proportion of people affected by rabies exposures globally

Immediate Action When a Pet Is Exposed to a Suspected Rabid Animal

An important responsibility of a pet owner is knowing what to do when an animal has been bitten, scratched, or otherwise exposed to a potentially rabid animal. Any suspected exposure should be reported promptly to a veterinarian or appropriate animal health authority. The owner should avoid handling saliva from the exposed animal unnecessarily and should prevent the pet from interacting with other animals or people. Veterinary authorities can determine whether vaccination is current, assess the nature of the exposure, evaluate the source animal where possible, and recommend appropriate observation, vaccination, quarantine, or

other public health measures in accordance with applicable national and local regulations. Owners should not assume that an apparently healthy pet is necessarily free from infection immediately after exposure. Rabies has an incubation period, and decisions regarding management should therefore be based on professional risk assessment rather than appearance alone.

Preventing and Reporting Bites

Pet owners are responsible for reducing the likelihood that their pets will bite people. Dogs should not be left unsupervised around young children, unfamiliar visitors, or individuals who may be unable to interpret canine behaviour. Owners should recognize warning signs such as fear, guarding, pain, agitation, and defensive behaviour. Every bite should be taken seriously. The owner should provide accurate information about the animal's vaccination status and cooperate with veterinary and public health authorities. Concealing a bite, withholding vaccination records, or allowing the animal to disappear after an exposure can delay risk assessment and place the victim at greater risk. An important public health principle is that a bite from an owned animal should not automatically be considered harmless. Even healthy pets require appropriate assessment following a bite, particularly in a rabies-endemic country.

Educating Family Members and the Community

Pet owners are also important health educators. Every member of a household should understand basic rabies prevention, including the importance of animal vaccination, avoiding unnecessary contact with unfamiliar animals, and seeking medical care immediately after a possible exposure. Children should be taught not to disturb animals while they are feeding, sleeping, injured, caring for puppies, or displaying abnormal behaviour. They should be educated to tell an adult immediately if they are bitten or scratched by dog, even if the injury appears minor. Pet owners can contribute to community awareness by encouraging neighbours to vaccinate their dogs and by supporting local rabies-control campaigns. This community-level participation is important because protecting one vaccinated pet does not by itself interrupt transmission in a population containing large numbers of susceptible free-roaming dogs.

Understanding Pre-Exposure and Post-Exposure Prophylaxis

Pet owners should understand the difference between pre-exposure prophylaxis (PrEP) and post-exposure prophylaxis (PEP). Pre-exposure prophylaxis refers to vaccination given before a potential exposure to rabies and is recommended for people with increased occupational

or epidemiological risk. Post-exposure prophylaxis is given after a suspected exposure and may include thorough wound washing, rabies vaccine, and rabies immunoglobulin when needed. Pet owners who travel internationally with their animals should also understand that rabies epidemiology varies geographically and should seek veterinary advice regarding vaccination and travel requirements.

Conclusion

Rabies is an almost universally fatal disease after the onset of clinical illness, but it is highly preventable through appropriate vaccination, responsible animal management, exposure prevention, and timely post-exposure care. Ultimately, the goal of responsible pet ownership should be viewed as part of the larger **"Zero by 30"** vision: ending human deaths from dog-mediated rabies by 2030. This will require sustained vaccination of dogs, effective dog-population management, accessible human PEP, surveillance, public education, and strong collaboration between communities and animal and human health systems. Therefore, pet owners have a direct role in protecting not only their own animals and families but also the wider community.

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Volume: 06 Issue No: 10

TRANSITIONING TOWARDS LOW-CARBON AGRICULTURE: A PATHWAY TO SUSTAINABILITY

Article ID: AG-VO6-I10-70

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Introduction

Climate change has made carbon management an important component of sustainable agriculture, food security and natural-resource conservation. Carbon footprinting provides a systematic approach for quantifying the greenhouse gas (GHG) emissions associated with a defined product, farm, activity, organisation or supply chain and expressing them as carbon dioxide equivalent (CO_2e). This enables different greenhouse gases, including carbon dioxide, methane and nitrous oxide, to be assessed using a common measurement unit.

Its importance is particularly evident in the global agrifood sector, where emissions arise from crop and livestock production, land-use change, food processing, transportation, packaging, retail and waste management. According to the Food and Agriculture Organization of the United Nations (FAO), global agrifood-system emissions reached approximately 16.5 billion tonnes of CO_2e in 2023, accounting for about 32% of global anthropogenic greenhouse gas emissions. These figures demonstrate that assessing the carbon footprint of food requires consideration of the entire value chain rather than only field-level emissions.

In India, carbon footprinting is particularly relevant because agricultural production is associated with major GHG sources such as enteric fermentation in livestock, rice cultivation, agricultural soils, nitrogen fertiliser use, residue management and farm energy consumption. At the same time, agricultural soils, crop residues, trees and agroforestry systems can store carbon and contribute to carbon sequestration. Consequently, carbon footprinting can help identify

emission hotspots and develop management strategies that improve fertiliser-use efficiency, water and energy management, soil organic carbon and climate resilience. Integrating emission mitigation with soil-carbon restoration, improved soil fertility and resource-use efficiency is essential for maintaining agricultural productivity and farm profitability.

Global Scenario of Carbon Footprinting

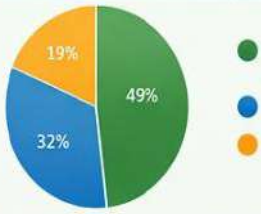
Greenhouse gas emissions remain a major global environmental concern. The United Nations Environment Programme (UNEP), through its Emissions Gap Report series, assesses the difference between projected global emissions and the reductions required to meet the temperature goals of the Paris Agreement.

According to UNEP's Emissions Gap Report 2024, global greenhouse gas emissions reached a record 57.1 billion tonnes of CO_2e in 2023, representing a 1.3% increase over 2022. The power sector was the largest contributing sector, followed by transport, agriculture and industry. This highlights the importance of coordinated mitigation efforts across energy, transport, industrial production and agrifood systems.

Global Agrifood-System Emissions (2023)

Total agrifood-system emissions: 16.5 billion tonnes CO_2e (≈ 32% of global anthropogenic GHG emissions)

Source	Emissions (billion tonnes CO_2e)	Share (%)
Farm-gate crop and livestock production	8.1	49%
Pre- and post-production (processing, transport, retail, etc.)	5.2	32%
Land-use change	3.2	19%
Total	16.5	100%



Source: FAO (2025). Greenhouse gas emissions from agrifood systems: Global, regional and country trends, 2001–2023.

The FAO's 2025 assessment of agrifood-system emissions provides further insight into the agricultural contribution to global emissions. In 2023, emissions within the farm gate from crop and livestock production accounted for 8.1 billion tonnes of CO_2e, representing 49% of agrifood-system emissions. Pre- and post-production activities contributed 5.2 billion tonnes of CO_2e, or 32%, while land-use change accounted for 3.2 billion tonnes of CO_2e, or 19%.

Although total agrifood-system emissions increased by 21% between 2001 and 2023, the emissions intensity of agricultural production declined by 25% over the same period. This indicates that agricultural production has become less emission-intensive relative to its economic output, even as the sector's overall emissions have increased.

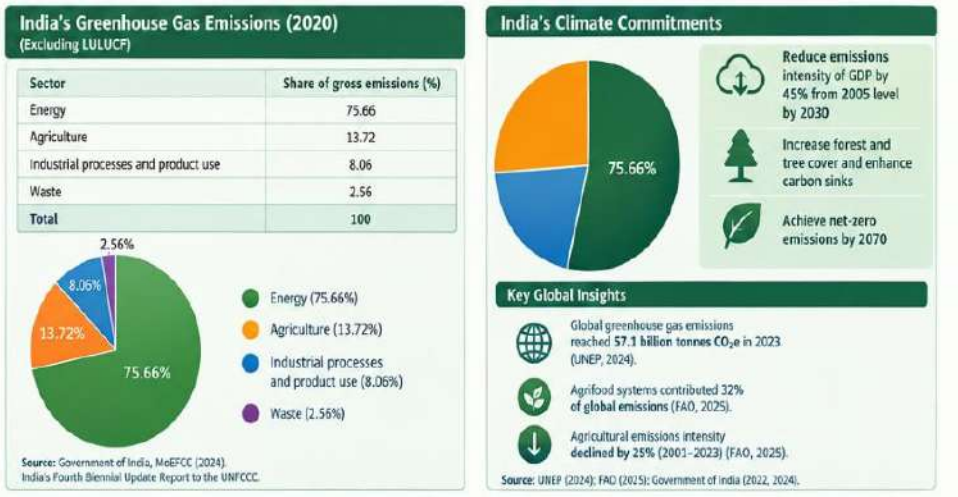
These findings emphasise the need to reduce emissions throughout the food value chain while improving agricultural productivity. Carbon footprinting provides a scientific basis for

measuring these emissions, identifying major contributors and evaluating the effectiveness of mitigation interventions.

Carbon Footprinting in India: National Scenario

India faces the dual challenge of sustaining economic growth and reducing greenhouse gas emissions while ensuring food security, livelihood protection and environmental sustainability. The Government of India has undertaken climate mitigation measures through national policies, renewable energy development, energy-efficiency initiatives, sustainable land management and climate-resilient agriculture.

According to India's Fourth Biennial Update Report, submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in December 2024, India's total greenhouse gas emissions in 2020 were approximately 2,959 million tonnes of CO_2e, excluding land use, land-use change and forestry (LULUCF). After accounting for the LULUCF sector, net emissions were approximately 2,436.7 million tonnes of CO_2e. The national inventory reported that the energy sector contributed 75.66% of emissions excluding LULUCF, followed by agriculture at 13.72%, industrial processes and product use at 8.06%, and waste at 2.56%. These figures demonstrate the importance of energy-sector decarbonisation while also recognising the need to address agricultural emissions through improved production practices.



India has also made progress in reducing the emissions intensity of economic activity. The official report indicates that emissions intensity of gross domestic product declined by 36% between 2005 and 2020. In addition, forest and tree cover, together with other land-use

categories, sequestered approximately 522 million tonnes of CO_2 in 2020, equivalent to around 22% of the country's total CO_2 emissions for that year, as reported by the Government of India. India's updated Nationally Determined Contribution includes a commitment to reduce the emissions intensity of GDP by 45% from the 2005 level by 2030. The country has also announced its long-term objective of achieving net-zero emissions by 2070. Carbon footprinting can support these objectives by enabling systematic assessment of emissions, monitoring progress and identifying cost-effective mitigation opportunities.

Carbon Footprinting in Agriculture: Major Emission Sources

Agriculture involves several biological and operational processes that contribute to greenhouse gas emissions. Identifying these sources is an essential step towards developing appropriate mitigation strategies.

Methane emissions: Methane is released through enteric fermentation in ruminant livestock and under anaerobic conditions in flooded rice fields. Appropriate livestock feeding, improved animal health, efficient manure management and suitable rice-water management practices can help reduce emissions.

Nitrous oxide emissions: Nitrous oxide is generated through microbial processes in agricultural soils, particularly where nitrogen availability and soil conditions favour its production. Excessive or poorly timed nitrogen fertiliser application can increase emissions and reduce nutrient-use efficiency. Soil-test-based fertiliser recommendations, split application and appropriate nutrient management can help improve efficiency.

Energy-related emissions: Diesel consumption in farm machinery, electricity used for irrigation, and energy required for harvesting, processing, storage and transportation contribute to the carbon footprint of agricultural commodities. Energy-efficient machinery, efficient irrigation systems and suitable renewable-energy technologies can reduce these emissions.

Crop residue and waste management: Open burning of crop residues releases greenhouse gases and air pollutants. Alternatives such as residue incorporation, composting, mulching and productive biomass utilisation can support resource recovery and reduce avoidable emissions.

Land-use change: Deforestation and the conversion of carbon-rich ecosystems into agricultural land can release substantial amounts of stored carbon. Protecting existing vegetation, restoring degraded land and integrating trees into agricultural landscapes can contribute to carbon conservation and sequestration.

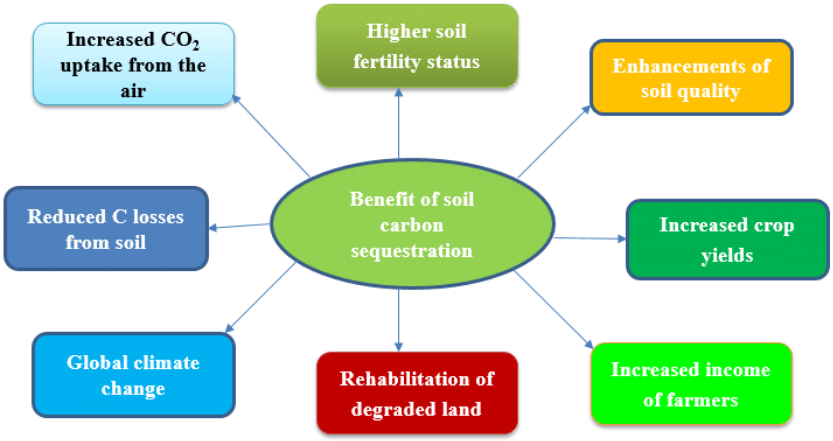
Carbon Sequestration and Soil Carbon Restoration

Carbon management in agriculture should address not only greenhouse gas emissions but also opportunities to store carbon in soils and vegetation. Soil organic carbon plays an important role in soil structure, nutrient cycling, water retention and long-term soil health.

Practices such as the application of suitable organic amendments, cover cropping, residue retention, reduced soil disturbance where appropriate, diversified cropping systems and agroforestry can contribute to soil-carbon maintenance or accumulation under suitable conditions. Their effectiveness depends on soil type, climate, management history and the duration of implementation.

Agroforestry and the integration of suitable trees into agricultural landscapes can store carbon in above-ground and below-ground biomass while providing additional benefits such as fodder, fuelwood, shade, biodiversity conservation and diversified farm income.

However, increases in soil organic carbon are not uniform across locations and cannot be assumed from the adoption of a practice alone. Baseline measurements, repeated soil sampling, suitable monitoring methods and long-term management are necessary to assess actual changes. Carbon sequestration should therefore be quantified alongside emissions to provide a more complete assessment of agricultural climate impacts.



Strategies for Reducing the Carbon Footprint of Indian Agriculture

Carbon footprint reduction requires locally suitable technologies that improve resource-use efficiency without compromising crop productivity, soil fertility or farmers' income.

- **Integrated nutrient management:** Combine soil-test-based fertiliser recommendations with appropriate organic nutrient sources and balanced fertilisation to improve nutrient-use efficiency.
- **Efficient water management:** Adopt irrigation scheduling, suitable micro-irrigation systems and improved rice-water management where feasible to reduce unnecessary water and energy use.
- **Climate-smart crop production:** Use suitable crop varieties, crop diversification, conservation practices and locally recommended agronomic technologies to improve resilience and resource efficiency.
- **Improved livestock management:** Enhance animal nutrition, health, breeding and manure management according to local conditions to improve productivity and reduce emission intensity.
- **Renewable energy adoption:** Promote technically and economically appropriate solar-powered irrigation, energy-efficient equipment and renewable-energy solutions.
- **Scientific crop-residue management:** Avoid open burning and promote residue recycling, composting, mulching or other productive uses based on local requirements.
- **Agroforestry and tree conservation:** Protect existing trees and introduce suitable tree-based systems where compatible with crop production, water availability and farm objectives.
- **Food-loss and waste reduction:** Improve harvesting, storage, processing, transportation and waste management to reduce emissions throughout the food supply chain.

The selection of these interventions should be based on local agroclimatic conditions, farm economics and measurable environmental outcomes. Their performance can be evaluated using carbon-footprint assessments alongside indicators such as yield, input-use efficiency, soil organic carbon and net farm returns.

Carbon Footprinting: A Tool for Climate-Smart Agriculture

Carbon footprinting involves defining the assessment boundary, collecting reliable activity data, applying appropriate emission factors and calculating emissions in CO_2e. Depending on the objective, an assessment may cover a single farm operation, a complete crop-production cycle, a product from production to the farm gate or the entire supply chain.

For agricultural applications, the assessment may include fertiliser use, irrigation energy, machinery operations, crop establishment, livestock-related emissions, residue management and relevant upstream inputs. If carbon sequestration is also assessed, changes in soil carbon and biomass carbon stocks should be estimated using appropriate methods.

A key consideration is the choice of functional unit. Emissions may be expressed per hectare, per kilogram of produce or per unit of economic output. These indicators answer different questions: emissions per hectare help assess land-based impacts, whereas emissions per kilogram of produce help compare production efficiency. The system boundary and methodology must remain consistent when comparing farms, technologies or products.

Krishi Vigyan Kendras, agricultural universities, research institutions and extension agencies can support this process by demonstrating improved management practices, training farmers, documenting field-level data and disseminating verified technologies. Such initiatives can strengthen evidence-based decision-making and encourage the adoption of climate-smart agricultural practices.

Conclusion

Carbon footprinting is an important scientific tool for understanding and managing the greenhouse gas emissions associated with agricultural production, food systems and economic activities. Global assessments by FAO and UNEP demonstrate the need to reduce emissions across the entire agrifood value chain, while India's national greenhouse gas inventory highlights the importance of addressing emissions from energy, agriculture, industry and waste.

For Indian agriculture, the way forward is to combine emission reduction with soil-carbon restoration, efficient nutrient and water management, improved livestock practices, renewable energy and agroforestry. These interventions must be assessed using reliable data and suitable measurement methods to ensure that environmental benefits are achieved without compromising productivity or farmers' livelihoods.

Ultimately, carbon footprinting can help transform climate commitments into measurable action by identifying emission hotspots, monitoring progress and supporting sustainable resource management. Integrating carbon accounting with climate-smart agriculture offers an important pathway towards improved soil health, resilient food systems and a more sustainable agricultural future for India.

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Volume: 06 Issue No: 10

THE CHEMICAL CONVERSATION UNDERGROUND: METABOLOMICS AND HIGH-RESOLUTION MASS SPECTROMETRY FOR UNDERSTANDING SOIL–MICROBE INTERACTIONS

Article ID: AG-VO6-I10-71

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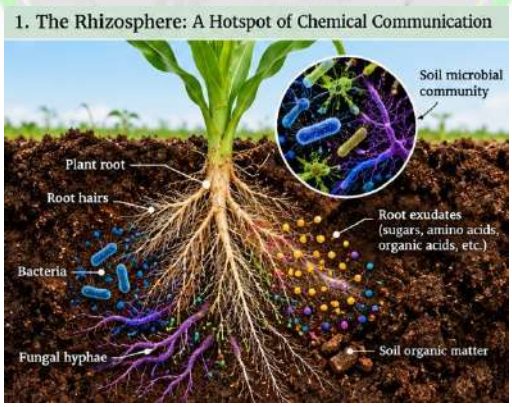
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Introduction

Walk across a field, a forest floor, or your own backyard, and you are standing on top of one of the most chemically complex environments on Earth. A single gram of healthy soil can harbor billions of bacterial cells, kilometers of fungal filaments, and an almost unimaginable diversity of small molecules — sugars leaking from root tips, signaling compounds released by bacteria, antibiotics deployed as chemical weapons, and the slow-cooked remains of dead organic matter. These molecules are not just debris. They are currency, signals, and weapons in a



nonstop negotiation between plant roots and the microbial communities that surround them.

For decades, soil scientists could describe this underground marketplace only in broad strokes: which nutrients were present, how much carbon was stored, which microbial groups dominated. What they could not easily do was read the individual molecular messages being exchanged — until the rise of two complementary tools, metabolomics and high-resolution mass spectrometry (HRMS), began to change that.

What Metabolomics Actually Measures

Metabolomics is the large-scale study of small molecules — sugars, amino acids, organic acids, lipids, and thousands of more exotic compounds — that are the end products of an organism's biochemistry. If genomics tells you what a cell could theoretically do, metabolomics tells you what it is actually doing right now. Applied to soil, this means capturing a molecular snapshot of everything that plants, bacteria, fungi, and other soil life are producing, consuming, and exchanging at a given moment.

The trouble is that soil is an analytical nightmare. It is a mixture of minerals, decaying plant tissue, living cells, and water films, all bound together with wildly different chemical properties. Extracting the metabolites cleanly, without introducing contamination or losing fragile compounds, is itself a major technical challenge, and classical soil-chemistry extraction methods — often built around concentrated salts — are notoriously incompatible with sensitive mass spectrometry instruments.

Why High Resolution Changes the Game

This is where high-resolution mass spectrometry earns its keep. Standard mass spectrometers separate ions by their mass-to-charge ratio, but at the resolution used in routine chemistry, thousands of different soil-derived molecules can produce overlapping, indistinguishable signals. HRMS instruments — most notably Fourier-transform ion cyclotron resonance mass spectrometry (FT-ICR-MS) and Orbitrap-based systems — resolve these signals with such precision that a molecule's exact elemental formula (its precise combination of carbon, hydrogen, oxygen, nitrogen, and sulfur atoms) can often be inferred directly from its mass.

That level of resolving power matters enormously in soil science, where organic matter is a bewildering mixture of tens of thousands of coexisting compounds. A recent methodological review noted that ultrahigh-resolution FT-ICR-MS is essentially the only technique with enough resolving power to assign individual molecular formulas across the full complexity of soil organic matter, making it the workhorse for untangling what soil carbon is actually made of.

A Quick Comparison of the Main Tools

Technique	What it does best	Typical soil–microbe application
FT-ICR-MS	Ultra-high mass resolving power; assigns molecular formulas to tens	Fingerprinting the full molecular complexity of soil organic matter

	of thousands of ions from a single infusion, no chromatography needed	and dissolved organic matter pools
LC-MS/MS	Separates compounds before ionization and fragments them for structural identification	Confirming the identity of specific root exudates, microbial signaling molecules, or antibiotics
Mass spectrometry imaging (e.g., LDI, MALDI)	Maps where a molecule sits within a thin tissue or soil section at micrometer resolution	Visualizing chemical gradients radiating outward from a living root into the surrounding soil
GC-MS	Excellent for small, volatile, or derivatized polar metabolites with strong reference libraries	Profiling sugars, organic acids, and amino acids extracted from bulk soil

Table 1. The main mass spectrometry approaches used to study soil–microbe chemistry, and what each is best suited to reveal.

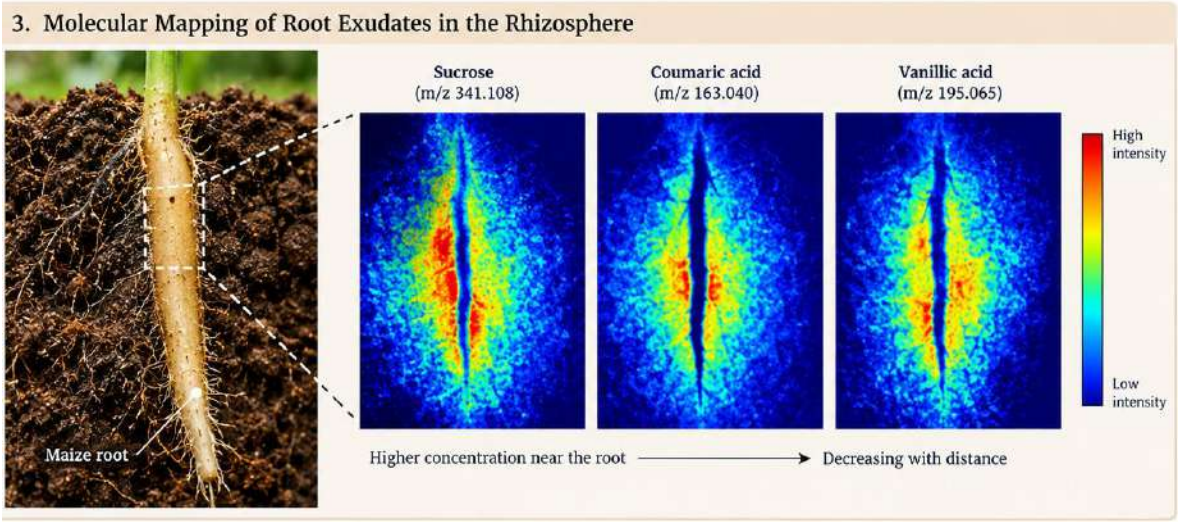


Watching Root Exudates Meet the Soil, Molecule by Molecule

One of the most vivid demonstrations of this technology comes from imaging mass spectrometry, which does not just identify molecules but maps exactly where they sit within a physical sample. Researchers working with maize (Zea mays) roots embedded intact soil sections and analyzed them using laser desorption ionization coupled to ultra-high-resolution FT-ICR-MS. Rather than grinding up soil and losing all spatial information, this approach preserved the natural architecture of the rhizosphere — the thin zone of soil directly influenced by roots.

The results were striking: sugars such as sucrose were found in high concentration right at the root surface, then dropped off sharply within about 150 micrometers — roughly the width of two or three human hairs — as microbes and soil minerals consumed or bound the molecules [1]. Other plant metabolites, including coumaric acid and vanillic acid, showed their own distinct spatial signatures. This kind of chemical cartography reveals, for the first time, how narrow and dynamic the true zone of root–microbe chemical exchange really is.

Complementary work has pushed spatial resolution even further by combining chemical imaging with direct microbial identification. By embedding intact rhizosphere samples in resin and analyzing them with a suite of correlated techniques — including secondary ion mass spectrometry and electron microscopy — scientists can now link specific microbial cells to the specific chemical microenvironments they inhabit, at scales approaching individual bacterial cells rather than bulk soil samples.



Reading the Molecular Fingerprint of Soil Carbon

Beyond the rhizosphere, HRMS has transformed how scientists think about soil organic matter itself — the vast, only partially understood reservoir of carbon that underlies soil fertility and global carbon cycling. Because soil organic matter is built from the combined leftovers of plant tissue, microbial biomass, and countless rounds of microbial processing, its molecular composition encodes a history of who ate what, and how thoroughly.

In one study of root litter decomposing under simulated drought versus normal moisture conditions, researchers combined direct-infusion FT-ICR-MS with tandem liquid chromatography-mass spectrometry and molecular networking to characterize the resulting

organic matter in far greater depth than either method could achieve alone. Under drought, they found a higher proportion of lignin-like and aromatic polyphenolic compounds and a lower average oxidation state of carbon — chemical evidence that microbial decomposition had slowed and organic matter was being broken down less completely [2]. That is a direct, molecular-level readout of how water stress reshapes the underground carbon economy, something that bulk carbon measurements alone could never reveal.

This kind of integrative approach — pairing the broad compositional sweep of FT-ICR-MS with the structural detail of tandem mass spectrometry — is becoming a standard strategy precisely because neither tool alone tells the whole story. FT-ICR-MS is superb at cataloguing thousands of molecular formulas in one measurement but cannot usually say what shape a given molecule takes; LC-MS/MS can nail down structures but only for the smaller subset of compounds that separate cleanly on a chromatography column and match existing spectral libraries.

The Microbial Side of the Conversation

Soil metabolomics is not only about what plants send into the soil — it is equally about what microbes send back. Bacteria and fungi secrete an enormous range of compounds collectively known as the exometabolome: organic acids that dissolve minerals, siderophores that scavenge scarce iron, quorum-sensing molecules that coordinate community behavior, and antimicrobial compounds that suppress rivals.

A recent review of soil metabolomics highlighted that water-soluble, bioavailable metabolites and volatile compounds are emerging as some of the most important information-carrying chemicals underlying soil–plant–microbe interactions, and that soil metabolomics is also proving useful for tracing how microbial activity directly contributes to the formation of stable, long-lived organic matter [3]. In other words, the humus that gives healthy soil its dark color and water-holding capacity is, in part, a byproduct of countless microbial metabolic transactions, each of which leaves a molecular trace that HRMS can now detect.

A broader synthesis of the field has emphasized just how much remains undiscovered: an estimated fewer than 14 percent of the compounds detected in typical untargeted metabolomics experiments can currently be confidently identified, a gap that is even more pronounced in understudied environments like soil [4]. Closing that annotation gap — building better reference libraries and computational tools to match unknown masses to real molecular structures — is

now considered one of the central bottlenecks in the field, and a major reason why exometabolomics is expanding from easily cultured microbial strains toward whole, uncultured microbial communities.

From the Lab Bench to Standardized Protocols

As interest in soil metabolomics has grown, so has the need for reliable, reproducible extraction and analysis protocols. Detailed methodological work has laid out step-by-step approaches for extracting small-molecule metabolites from soil and analyzing them using both liquid chromatography-mass spectrometry and gas chromatography-mass spectrometry, with options to focus on either the extracellular metabolite pool alone or the combined extracellular-and-intracellular pool, and to target either polar or nonpolar compound classes.

These protocols matter because the molecular composition of soil organic matter directly shapes which microbial communities can establish themselves and how efficiently carbon cycles through an ecosystem [5]. Standardizing how researchers pull metabolites out of soil — and being explicit about which fraction of the metabolome a given method captures — is essential if results from different laboratories and ecosystems are ever going to be compared meaningfully.

Why This Matters Beyond the Laboratory

It would be easy to file all of this under abstract chemistry, but the stakes are practical and large. Understanding the molecular dialogue between roots and microbes is central to designing more resilient, lower-input agriculture: microbes that help plants withstand drought or resist pathogens do so, in large part, by trading specific metabolites, and identifying those molecules is the first step toward harnessing beneficial soil microbiomes as a genuine alternative to synthetic fertilizers and pesticides.

The same molecular insight matters for climate science. Soil holds more carbon than the atmosphere and all plant biomass combined, and whether that carbon stays locked in the ground or is released as carbon dioxide depends heavily on the chemical form it takes and how accessible it is to microbial decomposers. Every time HRMS resolves a new class of molecules within soil organic matter, it sharpens scientists' ability to predict how soils will respond to a warming, drying world — and, potentially, how to manage land to keep more carbon underground.

Bioremediation and environmental cleanup are benefiting too. Because certain soil bacteria are capable of transforming toxic metals and organic pollutants into less harmful forms,

mapping the metabolic pathways and chemical byproducts involved gives engineers a rational basis for selecting or engineering microbial strains for contaminated sites, rather than relying on trial and error.

The Road Ahead

Soil metabolomics is still, by most accounts, in its early days. Instrumentation continues to improve — newer FT-ICR-MS systems built around stronger magnets are pushing resolving power and mass accuracy even higher, allowing scientists to distinguish molecules with almost identical masses but different chemical identities. Meanwhile, computational pipelines are being built specifically to handle the flood of data these instruments generate, since a single FT-ICR-MS run can produce hundreds of millions of individual data points.

The next frontier is arguably integration: combining chemical data with genomic and microscopy information so that a detected metabolite can be traced not just to a location in the soil, but to the specific organism, and even the specific gene, responsible for producing it. As reference libraries expand and machine-learning tools get better at proposing structures for unidentified masses, researchers expect the fraction of the soil metabolome that can be confidently named — currently a small minority of what is detected — to grow substantially over the coming decade.

For now, every soil sample analyzed by high-resolution mass spectrometry is a little like intercepting a conversation in a language we are still learning to translate. But with each new study, the vocabulary of that underground chemical conversation becomes a little clearer — and with it, our ability to work with, rather than against, the microscopic life that sustains nearly all terrestrial ecosystems.

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Volume: 06 Issue No: 10

MODERN AGRICULTURE: HOW SMART TECHNOLOGY AND NATURE-FRIENDLY FARMING

Article ID: AG-VO6-I10-72

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Abstract

By the year 2050, our planet will be home to nearly 9.7 billion people. Feeding everyone is one of the biggest challenges humanity has ever faced—especially when farmland is shrinking, fresh water is running low and the weather is becoming more unpredictable each year. This article explores how modern agriculture (often called 'Smart Farming' or 'Agriculture 4.0') is solving this problem. Instead of simply pouring more chemicals and water onto fields, today's farmers are combining everyday digital tools—like soil sensors, drones and artificial intelligence—with better seeds and nature-friendly practices that heal the soil. We also look at how small family farmers can afford these tools so that no community is left behind.

Keywords: Modern agriculture, Smart farming, Gene editing, Soil health and Food security

Introduction

If you walked onto a farm a hundred years ago, almost everything was done by hand or with the help of horses and oxen. Farmers relied on experience, the changing seasons and hard physical labor to grow food for their local communities. Then, in the middle of the 20th century, a massive shift happened known as the Green Revolution. Scientists developed stronger wheat and rice seeds that produced much bigger harvests and farmers began using tractors, chemical fertilizers, and pesticides on a huge scale (Tilman *et al*., 2011). This shift was a lifesaver—it tripled grain production around the world and prevented terrible famines across Asia and Latin America (Food and Agriculture Organization , 2022).

However, after decades of heavy industrial farming, the side effects started showing up. Treating soil like a lifeless factory wore it out. Today, food production uses about 70% of all the

fresh water humans take from rivers and underground reserves, and it creates roughly a quarter to a third of the world's greenhouse gas emissions (Foley *et al*., 2011; Intergovernmental Panel on Climate Change, 2022). When farmers spray too much fertilizer, the extra chemicals wash into rivers and lakes, harming fish and drinking water. At the same time, climate change is bringing longer droughts, sudden heatwaves, and unexpected floods that make it harder for crops to survive (Godfray *et al*., 2010).

This brings us to a major question: How do we grow 50% more food for a growing global population by 2050 without destroying the land and water we depend on? The answer is Modern Agriculture—often called 'Smart Farming' or 'Agriculture 4.0' (Klerkx *et al*., 2019; Rose & Chilvers, 2018). Modern farming is not about working harder or using more chemicals. It is about working smarter. By blending digital technology, better plant science, and deep respect for nature, modern farmers can give each plant exactly what it needs, right when it needs it.

Smart Farming: Giving Every Plant Exactly What It Needs

In traditional farming, a farmer usually treats an entire ten-acre field the exact same way. If one corner of the field looks dry or pale, the whole field gets watered or sprayed with fertilizer. That wastes money, water and chemicals. Modern agriculture changes this through an approach called Precision Agriculture (Gebbers & Adamchuk, 2010). Think of it like personalized healthcare, but for plants.

Soil Sensors and Smart Watering

Today, farmers can push small, affordable sensors into the dirt across their fields. These sensors act like a thermometer and moisture check for the earth, constantly measuring how wet the soil is, how warm it is, and whether the plants have enough nutrients (Wolfert *et al*., 2017). The sensors send this information straight to the farmer's smartphone. Even better, they can connect directly to drip irrigation pipes. When the soil gets dry, the water turns on automatically, delivering water drop by drop right to the plant's roots. Studies show that smart watering cuts water use by 25% to 40% while keeping crops healthier (Kamilaris *et al*., 2017).

Eyes in the Sky: Drones, Satellites, and Smart Tractors

Walking through hundreds of acres to check for bugs or sick plants takes days. Modern farmers use drones and satellites to do the job in minutes. Equipped with special cameras, drones fly over the fields and take pictures that spot plant stress—like thirst, nutrient hunger, or early

fungal disease—up to two weeks before a human eye could ever notice a yellow leaf (Basso & Antle, 2020).

Once the drone creates a map of the trouble spots, the farmer loads that map into a GPS-guided tractor. Using Variable Rate Technology (VRT), the tractor drives itself in perfectly straight lines and only sprays fertilizer on the exact patches that need help. Some modern farm machines even use artificial intelligence (AI) cameras that scan the ground as they roll along. In the blink of an eye, the computer tells the difference between a food crop and a weed, zapping only the weed with a tiny drop of weedkiller or a quick laser beam. This cuts chemical herbicide use by up to 80% (Kamilaris & Prenafeta-Boldú, 2018).

Table 1: How Farming Has Evolved from Hand Tools to Smart Technology

Farming Era	Main Tools Used	How Fields Were Managed	Impact on Food & Nature
Farming 1.0 (Traditional Era)	Hand tools, plows pulled by oxen or horses, animal manure	Small family plots managed by experience and guesswork	Low food output; very hard physical labor; gentle on nature
Farming 2.0 (Green Revolution)	Gas tractors, chemical fertilizers, pest sprays, big canals	Whole fields sprayed and watered evenly all at once	Huge jump in food supply; caused water pollution and worn-out soil
Farming 3.0 (Early Tech Era)	GPS steering for tractors, basic yield maps, early lab seeds	Fields divided into large zones based on soil type	Less wasted fuel and seed; better tracking of harvest size
Farming 4.0 (Modern Smart Era)	Soil sensors, drones, AI cameras, gene-edited seeds, phone apps	Plant-by-plant care in real time	Saves 20–40% water and up to 80% weedkiller; protects soil life

Better Seeds and Growing Food Indoors

Tougher Seeds Through Gene Editing (CRISPR) and Helpful Microbes

Technology in the field is only half the story; the other half happens inside the seed itself. For thousands of years, farmers saved seeds from their best plants to grow stronger crops the next season, a slow process that took decades. Later, in the 1990s, scientists created genetically modified (GM) crops by adding genes from other species, which made many shoppers nervous. Today, scientists use a much cleaner, more natural tool called CRISPR gene editing (Chen *et al*., 2019; Gao, 2021).

Think of CRISPR like the 'find and replace' tool in a word processor. Instead of adding foreign DNA, scientists simply tweak a plant's own existing genes to wake up its natural strengths. Using this method, researchers have developed wheat that shrugs off mold, rice that survives salty or flooded soil, corn that stays green during droughts, and crops packed with extra vitamins and iron for children (Gao, 2021; Qaim, 2020). At the same time, scientists are coating seeds with friendly soil bacteria and fungi—almost like probiotics for plants—that help roots pull natural nitrogen straight from the air, cutting down the need for chemical fertilizers.

Vertical Farming: Growing Greens in the City

What if we could grow fresh food right inside crowded cities, inside empty warehouses or skyscrapers, without needing any soil at all? That is the idea behind Controlled-Environment Agriculture (CEA) and vertical farming (Benke & Tomkins, 2017; Despommier, 2010). In these indoor farms, plants sit on stacked shelves under glowing LED lights that mimic sunshine. Their roots are misted with nutrient-rich water (aeroponics) or sit in flowing water trays (hydroponics).Because the building is sealed off from the outside world, there are no droughts, no hailstorms, and no bugs—which means zero pesticides are needed. Even better, the water that evaporates from the leaves is captured and reused, saving up to 95% more water than open-field farming. While running all those LED lights uses too much electricity to profitably grow heavy staple crops like wheat or potatoes (Asseng et al., 2020), vertical farms are fantastic for growing crisp lettuce, spinach, herbs, and strawberries year-round right next to neighborhood grocery stores.

Working With Nature: Regenerative and Climate-Smart Farming

Perhaps the most exciting shift in modern agriculture is the realization that high-tech gadgets work best when paired with old-fashioned respect for nature. Scientists call this Climate-

Smart and Regenerative Agriculture (Lipper *et al.*, 2014). Instead of fighting nature, regenerative farmers focus on bringing the dirt back to life. Healthy soil is not just brown dust; a single teaspoon of healthy farm soil holds billions of helpful bacteria, fungi, and earthworms that feed plants and trap carbon underground (Lal, 2015).

Four simple, nature-friendly habits are transforming modern farms around the world:

Leaving the Plow in the Shed (No-Till Farming): For generations, farmers plowed their fields every spring to flip the soil over. We now know that heavy plowing tears up earthworm tunnels, dries out the dirt, and lets wind blow away the best topsoil. With no-till farming, farmers leave last year's crop stalks on the ground as a protective blanket and poke new seeds directly into the earth, saving 50% to 70% on tractor fuel and keeping water in the ground (Lal, 2015).

Planting 'Cover Crops' Between Harvests: Nature hates bare dirt. Instead of leaving fields empty and muddy after the autumn harvest, modern farmers plant cover crops like clover, vetch, or radishes. These plants hold the soil together during winter rains, choke out weeds naturally, and add free nutrients back into the earth when spring arrives.

- **Mixing Trees and Crops (Agroforestry):** Planting rows of fruit, nut, or timber trees alongside crops and grazing cattle gives animals shade during hot summers, blocks strong winds, gives birds a home, and gives the farmer an extra source of income (Pretty *et al.*, 2018).
- **Fighting Bugs with Bugs (Integrated Pest Management):** Instead of spraying an entire orchard with harsh chemicals at the first sign of pests, farmers release helpful insects like ladybugs, use scent traps to confuse harmful moths, and rotate different crops each year so pests cannot get comfortable.

Table 2: Real-World Benefits and Everyday Challenges of Modern Farming Tools

Modern Tool or Practice	How It Helps the Harvest	What It Saves	Main Hurdle for Farmers
GPS Tractors & Smart Spreaders	Boosts harvest consistency by 5% to 15% across uneven fields	Cuts fertilizer and tractor fuel bills by 15% to 30%	Machinery is very expensive for small farmers to buy upfront

Soil Moisture Sensors & Drip Lines	Increases crop growth by 10% to 25% in dry regions	Saves 25% to 40% of fresh water; keeps rivers clean	Requires reliable rural internet and occasional repairs
AI 'See-and-Spray' Weed Robots	Protects crops from chemical burn, boosting yields up to 8%	Reduces weedkiller chemical sprays by 60% to 85%	Cameras need training to recognize local weeds in different regions
CRISPR Gene-Edited Seeds	Protects 12% to 30% of the harvest during droughts or plant sickness	Fewer fungicide sprays needed; less food rots in storage	Different countries have different rules and laws on gene editing
No-Till & Winter Cover Crops	Keeps yields steady during dry years as soil gets spongier	Cuts soil erosion by 60% and traps carbon underground	Takes 3 to 5 years for worn-out soil to fully bounce back

Making Sure Small Family Farmers Are Not Left Behind

When we read about self-driving tractors and flying drones, it is easy to picture giant corporate farms spanning thousands of acres. But here is a reality check: about 84% of all farms in the world are small family plots under five acres, and these hardworking smallholder farmers grow roughly a third of the world's food, especially across India, Southeast Asia, Africa, and Latin America (Lowder *et al*., 2016). A farmer with two acres of land cannot afford a hundred-thousand-dollar robot tractor. If modern agriculture only helps wealthy mega-farms, rural families will suffer (Klerkx *et al*., 2019).

Thankfully, smart technology is becoming cheaper and easier to share. Across developing nations, farmers are using simple smartphone apps that let them snap a photo of a sick leaf and get an instant, free diagnosis along with advice in their local language. Instead of buying expensive machines, village cooperatives and 'Uber-for-tractor' rental services allow small farmers to rent a drone or a precision seeder for just a few hours at an affordable rate (FAO, 2022). At the same time, governments and farmer groups are working to make sure that the data collected from family farms belongs to the farmers themselves, not just big tech companies.

In the end, the future of food is not a choice between high-tech gadgets and traditional care for the land—it is the marriage of both. When we combine the wisdom of healthy soil with the pinpoint accuracy of modern science, and when we put affordable tools into the hands of everyday farmers, we can grow plenty of nutritious food for ten billion people while leaving the earth greener and healthier for our grandchildren.

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Volume: 06 Issue No: 10

FRUIT FLY PESTS: HOST CROPS, DAMAGE AND SUSTAINABLE MANAGEMENT

Article ID: AG-VO6-I10-73

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Abstract

Fruit flies are among the most destructive insect pests in fruit and vegetable production. They cause direct damage by ovipositing inside fruit, where the developing maggots feed on the fruit pulp, causing rot, premature fruit drop and reduced market quality. Different species of fruit flies attack mango, guava, cucumber, bitter gourd, pumpkin and other cucurbits. Effective management includes early monitoring, field sanitation, suitable traps, protective fruit bagging and other integrated pest management practices. By using these measures farmers can reduce crop losses, minimize unnecessary pesticide use and improve the quality of their produces.

Keywords: Fruit flies, *Bactrocera dorsalis*, *Zeugodacus cucurbitae*, mango, guava, cucurbits, integrated pest management.

Introduction

Tephritid fruit flies are important agricultural pests of the family Tephritidae (order Diptera). They are serious polyphagous pests in fruit crops causing major economic loss. Unlike many insects that feed on the outside of leaves or stems, female fruit flies lay their eggs inside developing or mature fruits. When they hatch, the larvae, known as maggots, feed inside the fruit and are protected from many outside control measures. In India, the oriental fruit fly, *Bactrocera dorsalis*, is a major pest of mango and many other fruit crops. The melon fly, *Zeugodacus cucurbitae*, attacks many species of cucurbit vegetables. These pests affect the quantity and quality of the produce and can also pose problems for farmers in marketing and exporting the fruit. Severe yield loss by pre-mature fruit dropping (40 to 90 %). Integrated management including sanitation, trapping and preventive measures is therefore essential.

Major fruit fly pests

Fruit flies may resemble ordinary houseflies but their biology and feeding habits make them especially damaging to horticultural crops.

Oriental fruit fly (*Bactrocera dorsalis*)

The species attacks mango and a number of other tropical fruits. The female lays eggs under the fruit skin with her ovipositor. Maggots consume the pulp, causing internal damage and decay.

Melon fly (*Zeugodacus cucurbitae*)

The melon fly is an important pest of cucurbit vegetables like bitter gourd, cucumber, pumpkin and other gourds. Infested fruits may become deformed, develop patches of rotting and fall prematurely. Other fruit fly species also attack crops like guava, papaya and citrus.

Life cycle

Life cycle of fruit flies involves complete metamorphosis. Fruit flies go through four developmental stages: egg, larva, pupa and adult.

Egg: Female deposits eggs under the skin of fruits or in suitable plant tissues.

Larva: The maggot emerges from eggs and feeds on fruit pulp, resulting in internal damage to fruits.

Pupa: Matured larvae generally come out of the fruit and pupate in soil.

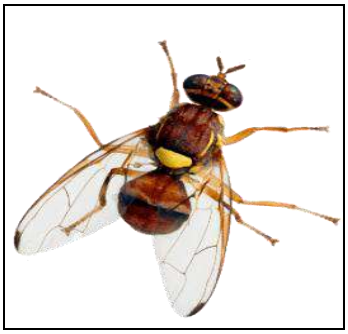
Adult: Adults emerge from pupae, mate and reproduce if suitable hosts are available.

Time required for completion of life cycle varies depending upon the species, temperature, humidity and hosts. As larvae develop inside fruits and pupae usually develop in soil, control measures have to be taken against not only adults but also other developmental stages.

Symptoms

- Small puncture marks on the fruit surface.
- Soft or discoloured patches at the sites of egg laying.
- Oozing from the damaged fruit.
- Maggots in the pulp.
- Premature fruit drop and internal rot.
- Deformed or unmarketable fruit (especially in the cucurbits).

The secondary microorganism can enter through damaged tissue and hasten decay. Even fruits that appear relatively normal externally may contain larvae, making careful inspection important.



Fruit fly (*B. dorsalis*)



Damage symptom



Parapheromone lure trap

Mango orchards

Management of mango fruit fly should be initiated before any serious damage to fruit is evident. Susceptible varieties: Bangalora, Neelum, Alphonso and Banganapalli.

- **Sanitation in the orchard:** Removal of fallen and damaged mangoes regularly. Proper disposal of such fruit to prevent emergence of any surviving larvae.
- **Use proper traps:** Traps based on methyl eugenol can attract male *B. dorsalis* and some related species. They should be placed and maintained as per the recommended local programme.
- **Use bait-based management wherever appropriate**: Protein baits or other registered bait formulations can be used to attract adult flies. Use only products recommended for the crop.
- **Reduction of soil stage survival:** Proper soil management of the orchard, including cultivation where agronomically feasible, can result in exposing the pupae to predators and environmental factors.
- **Coordination of management:** Sanitation and trapping at community level may be more effective than individual effort of farmers

Protecting guava fruits

Fruit flies are particularly attracted to guava fruits when the suitable fruits are available for egg laying. Farmers can do the following to minimize damage. Susceptible varieties: Arka kiran, Lucknow-49.

- **Bag the fruits:** Place suitable fruit-protection bags over suitable developing guava fruits to prevent adult flies laying eggs.
- **Remove and destroy infected fruits:** Collect fallen, damaged and rotting guavas regularly.
- **Dispose of infested fruits safely**: Use an approved disposal method to keep larvae from surviving and developing.
- **Monitor adult flies:** Use locally recommended fruit fly traps and check traps regularly.
- **Control orchard sanitation:** Remove neglected and overripe fruits that may harbor continued pest development.

Managing fruit flies in vegetable crops

Fruit flies are major pests of cucurbit vegetables such as bitter gourds, cucumbers, pumpkins, bottle gourds, ridge gourds and related crops. Their damage can result in significant losses because the maggots feed inside the developing fruit, rendering infested produce unsaleable.

Practical management measures include:

1. Check fruits often for holes, oozing and beginning to rot.
2. Pick damaged and fallen fruit during the season.
3. Install appropriate fruit fly traps before populations reach high levels.
4. Use crop rotation and appropriate planting schedules.
5. Practice field sanitation after harvest to reduce carry over of the pest.

Traps: An important tool in fruit fly management

- **Methyl eugenol traps:** These attract males of *B. dorsalis* and several related species. They are widely used in mango and other fruit crops.
- **Cucurbit fruit fly lures:** Species-specific attractants, including commercially developed products, may be used for melon fly management. The lure must match the target pest.
- **Food and protein-based baits:** These attract flies seeking food and may be incorporated into approved bait-based control methods.

Challenges and future prospects

Management of fruit flies is complicated by the wide host range of some species, the hidden development of larvae, the constant availability of host plants and the transport of

infested fruits between sites. Weather and the availability of crops in different seasons can also affect pest populations. Future management could be improved by better attractants, species-specific monitoring, digital pest surveillance systems, safer bait formulations and coordinated area-wide control programs. Training and co-operation with neighboring farms can help farmers to improve sanitation and trap effectiveness.

Conclusion

Fruit flies are a serious threat to fruit and vegetable production with major losses in yield and quality. Integrated pest management through field sanitation, appropriate trapping, fruit bagging and regular monitoring can help farmers control infestations, protect their harvests and promote sustainable horticulture.

Volume: 06 Issue No: 10

REMOTE SENSING AND GIS: TRANSFORMING MODERN AGRICULTURE AND FISHERIES

Article ID: AG-VO6-I10-74

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Abstract

The ability to observe agricultural fields and aquatic environments from space is transforming the way natural resources are monitored and managed. Agriculture and fisheries are increasingly influenced by climate variability, environmental degradation, resource limitations and the growing demand for sustainable food production. Conventional field-based observations alone may not provide sufficient spatial and temporal information to monitor these rapidly changing systems. Remote sensing and Geographic Information Systems (GIS) offer powerful tools for observing, analysing and managing agricultural and aquatic environments over large areas. In agriculture, satellite-based observations support crop mapping, crop-health assessment, drought monitoring, precision agriculture and production estimation. In fisheries, remote sensing provides valuable information on sea-surface temperature, chlorophyll-a, ocean productivity, potential fishing zones and aquatic habitats. GIS further enables the integration of satellite observations with environmental, biological and socioeconomic information to support spatial planning and decision-making. The integration of remote sensing, GIS, field observations and emerging technologies such as artificial intelligence can improve resource-use efficiency and strengthen sustainable management. This article highlights the major applications, benefits, limitations and future prospects of remote sensing and GIS in modern agriculture and fisheries, with particular emphasis on their role in supporting evidence-based and environmentally sustainable resource management.

Introduction

Agriculture and fisheries depend strongly on the environment. Crop growth is influenced by soil, rainfall, temperature, moisture and nutrient availability, while fish distribution is closely associated with water temperature, productivity, currents, depth and habitat conditions. Traditionally, information about these factors has been obtained through field surveys and direct observations. Although field observations remain essential, they can be time-consuming, expensive and difficult to conduct over large geographical areas.

Remote sensing and Geographic Information Systems (GIS) have transformed this situation by allowing researchers, farmers, fisheries managers and policymakers to observe and analyse environmental conditions over large areas. Remote sensing provides information about the Earth's surface and oceans without requiring direct physical contact, while GIS allows information from different sources to be stored, analysed and displayed spatially. Together, these technologies provide an important foundation for modern, data-driven resource management (Meaden & Aguilar-Manjarrez, 2013).

The increasing availability of satellite observations has made remote sensing particularly valuable because satellite data can provide repeated observations over large areas. In agriculture, satellite-based monitoring is already used for crop area estimation, crop-condition assessment, production estimation and soil-related studies in India (ISRO, 2026).

"Landsat and agriculture go hand in hand because agriculture is a seasonal phenomenon, and you really need to monitor it closely over time."

— Darrel Williams

Understanding Remote Sensing and GIS

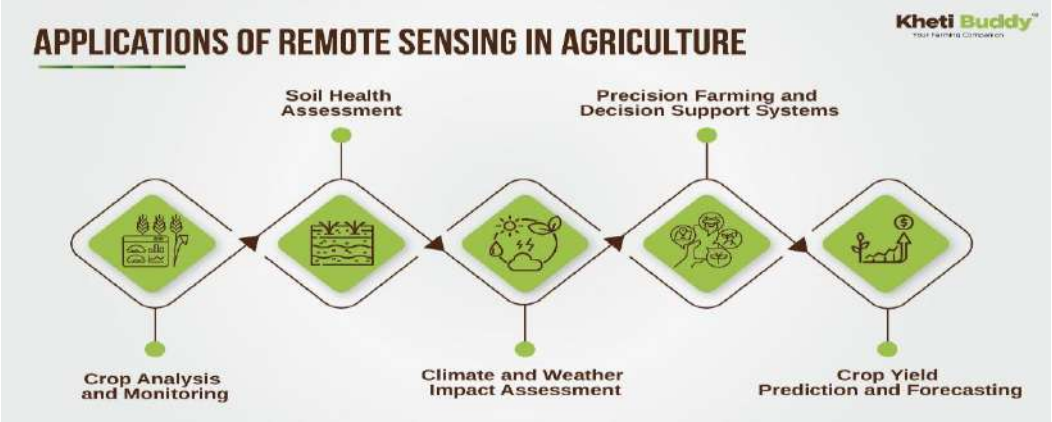
Remote sensing involves obtaining information about an object or environment from a distance, generally using sensors mounted on satellites, aircraft or unmanned aerial vehicles (UAVs). These sensors record electromagnetic radiation reflected or emitted from the Earth's surface. Different materials interact with electromagnetic radiation differently, allowing features such as vegetation, water bodies, soil and built-up areas to be identified.

Satellite missions provide data in different spectral regions and at different spatial and temporal resolutions. Multispectral and hyperspectral observations can provide information about vegetation characteristics, water properties and environmental conditions. In agriculture,

vegetation indices derived from satellite imagery can help identify differences in crop growth and stress (Sishodia *et al*., 2020; Shafi *et al*., 2023).

GIS complements remote sensing by providing a framework for managing and analysing geographically referenced information. Satellite imagery can be combined with layers such as soil type, rainfall, topography, roads, water bodies, land use and administrative boundaries. This makes it possible to identify spatial patterns and support management decisions.

In simple terms, remote sensing helps us observe the environment, while GIS helps us understand where those observations occur and how different factors are related.



(Source: Kheti Buddy, 2024)

Applications in Agriculture

Crop monitoring and mapping

One of the major applications of remote sensing in agriculture is crop mapping. Satellite images can be used to identify cultivated areas and distinguish between different crop types based on their spectral characteristics and seasonal growth patterns.

Repeated satellite observations are particularly useful because crop growth changes continuously throughout the growing season. Changes in vegetation indices can therefore provide information about crop development and condition. Satellite-based crop monitoring has become an important source of spatial and temporal information for agricultural decision-making (Wu *et al*., 2023).

Monitoring crop health

Healthy vegetation absorbs visible red light and reflects a relatively large amount of near-infrared radiation. Vegetation indices such as the Normalized Difference

Vegetation Index (NDVI) use these spectral differences to provide information about vegetation condition.

Variations in vegetation indices may indicate differences in crop vigour, water availability or other environmental stresses. More advanced multispectral and hyperspectral approaches can provide additional information about crop physiological characteristics and stress conditions (Shafi *et al*., 2023).

Drought and water-stress assessment

Water availability is one of the major constraints on agricultural production. Remote sensing can help identify spatial differences in vegetation condition and surface moisture, allowing areas experiencing water stress to be identified.

Combining satellite observations with meteorological information and GIS can provide a more comprehensive picture of drought conditions. Such approaches are increasingly important for agricultural planning, particularly under changing climatic conditions.

Precision agriculture

Precision agriculture aims to manage agricultural fields according to their spatial variability rather than treating an entire field as uniform. Remote sensing, GIS, GPS and sensor technologies can therefore be combined to guide the application of water, fertilizers, pesticides and other inputs.

Remote sensing-based precision agriculture can support variable-rate management by identifying areas of different crop conditions within a field (Sishodia *et al*., 2020). GIS can then integrate these observations with soil, weather and field-management information to assist decision-making.

Crop forecasting

Satellite observations can also contribute to crop acreage and production estimation. In India, the Indian Space Research Organisation (ISRO) reports the use of satellite remote sensing for crop area estimation, crop yield and production estimation, crop-condition monitoring, soil information and related agricultural applications.

Thus, remote sensing can contribute not only to farm-level management but also to regional and national agricultural planning.

Applications in Fisheries

The value of remote sensing is not restricted to land.

Oceans, coastal waters and inland water bodies can also be monitored using satellite observations.

Potential Fishing Zones

One of the most important applications of remote sensing in Indian fisheries is the identification of Potential Fishing Zones (PFZs).

Fish do not distribute randomly in the ocean. Their distribution is influenced by environmental conditions and food availability. Satellite-derived sea-surface temperature (SST) and chlorophyll-a provide information about important physical and biological characteristics of the marine environment.

Oceanographic features such as fronts, eddies, upwelling zones and productive waters may be associated with fish aggregation. Combining satellite-derived SST and chlorophyll information can therefore help identify areas that may have favourable conditions for particular fisheries (Solanki *et al*., 2005).

In India, the Indian National Centre for Ocean Information Services (INCOIS) uses remote-sensing information to support operational PFZ advisory services. Its products incorporate parameters including SST, chlorophyll and bathymetry, and PFZ information is distributed through maps and web-based services.

This demonstrates how satellite remote sensing can move from research laboratories into practical fisheries management and fishing operations.

Ocean productivity and chlorophyll-a

Chlorophyll-a is widely used as an indicator of phytoplankton biomass and is therefore an important proxy for ocean productivity. Satellite ocean-colour observations can provide information on chlorophyll concentration across large areas.

INCOIS provides near-real-time ocean-colour products including chlorophyll, SST and other parameters that support applications such as PFZ advisories and monitoring of ocean biological conditions.

By combining chlorophyll information with fisheries observations, researchers can investigate relationships between environmental productivity and fish distribution.

Fish-habitat mapping

Remote sensing and GIS can also be used to investigate fish habitats. Environmental layers such as SST, chlorophyll, depth, currents and substrate characteristics can be combined to understand

the spatial distribution of suitable habitats.

GIS provides an effective framework for integrating these datasets and producing habitat maps. Such approaches can contribute to fisheries research, ecosystem-based management and spatial planning (Meaden & Aguilar-Manjarrez, 2013).

Coastal ecosystem monitoring

Coastal ecosystems such as mangroves, coral reefs, seagrass beds and estuaries provide important habitats and nursery grounds for many aquatic organisms. Their large spatial extent makes satellite remote sensing particularly useful for mapping and monitoring changes.

INCOIS identifies coral reef mapping and reef-health monitoring, phytoplankton monitoring, suspended sediment monitoring and SST observations among applications of remote sensing in marine environments.

Repeated satellite observations can therefore help identify changes in coastal habitats and support conservation and management programmes.

Remote Sensing and GIS in Aquaculture

Aquaculture requires suitable environmental conditions for successful production. Factors such as water temperature, salinity, water availability, land use, proximity to infrastructure and environmental sensitivity can influence site suitability.

GIS-based multi-criteria evaluation can combine several environmental and socioeconomic factors to identify suitable locations for aquaculture development. FAO has documented the use of GIS, remote sensing and mapping for marine aquaculture development and management, including site-selection and spatial-planning applications (Kapetsky & Aguilar-Manjarrez, 2007).

For inland aquaculture, GIS can similarly integrate information on water bodies, land characteristics, accessibility, infrastructure and environmental conditions.

GIS as a Decision-Support Tool

The real strength of these technologies comes from their integration.

For example, a fisheries researcher may combine:

Satellite imagery + SST + chlorophyll-a + bathymetry + currents + fish-catch data + GIS

to investigate potential fishing grounds.

Similarly, an agricultural planner may combine:

Satellite imagery + NDVI + soil characteristics + rainfall + irrigation information + GIS

to identify areas requiring different management strategies.

GIS therefore acts as a bridge between raw environmental observations and practical decision-making. It can convert complex datasets into maps that are easier for researchers, managers and policymakers to interpret.

Emerging Role of Artificial Intelligence

The rapid growth of satellite data has created both opportunities and challenges. Large volumes of imagery require efficient processing and interpretation. Artificial intelligence (AI) and machine learning are increasingly being combined with remote sensing to classify land cover, identify crop types, detect environmental changes and predict spatial patterns.

In agriculture, machine-learning approaches can improve the interpretation of multispectral and hyperspectral imagery and support crop monitoring. In fisheries, remote sensing can be combined with environmental and fisheries datasets to improve habitat modelling and understand species–environment relationships (Yen & Chen, 2021).

The future is therefore likely to involve the integration of satellites, GIS, AI, field sensors, drones and real-time environmental observations rather than reliance on a single technology.

Challenges and Limitations

Despite its advantages, remote sensing does not completely replace field observations.

Cloud cover can limit the availability of optical satellite imagery. Some environmental variables cannot be measured directly from satellites and must instead be estimated using indirect relationships. Underwater habitats can also be difficult to observe because water depth, turbidity and water-column conditions affect the signal reaching a satellite sensor.

Similarly, satellite-derived indicators do not automatically provide information about fish abundance. PFZ information indicates areas with environmental characteristics associated with potential fish aggregation; actual fish distribution can change because of species behaviour, oceanographic conditions and other ecological factors. Therefore, field observations and fisheries data remain essential for validation.

Another challenge is the technical expertise required to process and interpret remotely sensed data. Data quality, spatial resolution, temporal resolution, atmospheric effects and appropriate validation must all be considered when developing operational applications (Wu *et al*., 2023).

Future Prospects

The future of remote sensing and GIS in agriculture and fisheries is likely to be increasingly integrated and data-driven. Higher-resolution satellites, frequent observations, UAVs, cloud

computing and AI are making it possible to analyse environmental changes at increasingly fine spatial and temporal scales.

In agriculture, these technologies may support more precise irrigation, fertilizer management, crop-stress detection and yield forecasting. In fisheries, they can contribute to habitat mapping, PFZ advisories, ecosystem monitoring, climate-impact assessment and spatial fisheries management.

For India, the continued development of satellite-based services by organisations such as ISRO and INCOIS provides an important foundation for applying Earth-observation technology to agriculture, fisheries and environmental management. INCOIS currently uses remotely sensed SST and ocean-colour information for services including PFZ advisories, harmful algal bloom monitoring, coral bleaching, marine heat-wave applications and ocean forecasting.

Conclusion

Remote sensing and GIS have changed the way agricultural and aquatic environments can be observed and managed. Instead of depending exclusively on isolated field observations, researchers and resource managers can now obtain repeated, spatially extensive information and combine it with ground observations through GIS.In agriculture, these technologies support crop mapping, crop-health monitoring, drought assessment, precision farming and production estimation. In fisheries, they provide information on ocean conditions, productivity, potential fishing zones and aquatic habitats.

However, the greatest value of remote sensing and GIS lies not in replacing field-based science, but in complementing it. The integration of satellite observations, GIS, field measurements, fisheries information, artificial intelligence and local knowledge can provide a stronger scientific basis for sustainable resource management.As agriculture and fisheries face increasing pressures from climate variability, resource depletion and environmental change, remote sensing and GIS are likely to become increasingly important tools for building more efficient, informed and sustainable food systems.

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Volume: 06 Issue No: 10

THE HIDDEN PHYSIOLOGISTS: HOW MICROBES REGULATE HUMAN BODY FUNCTIONS

Article ID: AG-VO6-I10-75

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Abstract

The human body is a complex ecosystem which hosts trillions of microbes. Collectively known as the human microbiome, the microscopic inhabitants influence physiological processes extending beyond digestion, including nutrient metabolism, immune regulation, hormonal signaling and communication between the gut and brain. Through the production of biologically active metabolites, microbes interact with human cells and contribute to the maintenance of internal balance. Recent research has advanced our understanding of the interactions, revealing associations between microbial communities, dietary patterns and metabolic health. Researchers are also investigating how microbial signals travel between the intestine and distant organs. Although the discoveries offer promising opportunities for healthcare, many relationships remain under investigation. The article explores how microbes function as hidden physiological partners and how emerging research may reshape our understanding of human health.

Keywords: Gut brain axis, human microbiome, physiology, immune regulation, microbial ecology, metabolites.

Introduction

When we think about our body, we usually picture organs such as the brain, heart, intestine and liver working together to sustain life. Another remarkable community operates alongside the organs: the microbes which inhabit our bodies. Archaea, bacteria, fungi, and viruses occupy the skin, mouth, intestine and other body environments, forming complex microbial communities. For many years, microbes were primarily studied as agents of infectious

disease. Research has increasingly demonstrated that many of our microbial residents participate in processes essential to normal physiology. They help break down dietary components, produce bioactive compounds, interact with immune cells and influence the intestinal environment. The term microbiota refers to the microbes present in a given environment, whereas microbiome is commonly used for the microbes and their collective genetic material, although definitions vary. Together, the communities form a dynamic biological ecosystem that responds to diet, medication, age and environmental conditions. Scientists are investigating an intriguing possibility: the microbiome does not simply respond to what happens inside the human body; it also helps influence how the body functions.

The Intestine: A Microbial Centre of Metabolism

The digestive system provides one of the clearest examples of cooperation between humans and microbes. Human digestive enzymes can't completely break down every component of food, particularly certain complex dietary fibers. The substances reach the large intestine, where specialized microbes ferment them and produce smaller molecules. Among the most important products are short chain fatty acids (SCFAs), particularly acetate, propionate and butyrate. These compounds are not merely waste products of microbial activity. They can interact with receptors on human cells, influence gene regulation and contribute to intestinal and metabolic physiology. Butyrate, for example, serves as an important energy source for cells lining the colon. SCFAs also influence intestinal barrier integrity and immune responses. Their effects depend on the molecule, its concentration, the tissue involved and the physiological condition of the host. It highlighted how microbial metabolism connects dietary fiber with physiological functions, while also emphasising the complexity of these interactions this relationship provides a useful reminder that food does more than nourish human cells directly. It supplies raw materials for microbial communities, whose metabolic products may influence the body in return (Mukhopadhya and Louis, 2025).

Educators of the Immune System

The immune system must identify harmful pathogens while avoiding unnecessary attacks against harmless substances and beneficial Microbes. Maintaining this balance is essential because excessive inflammation can damage healthy tissues, whereas inadequate immune responses can increase susceptibility to infection. The microbiota contributes to this process through continuous interactions with intestinal cells and immune tissues. Some beneficial

Microbes compete with pathogens for nutrients and attachment sites, making it harder for harmful organisms to establish themselves. This protective effect is known as colonization resistance. Microbial components and metabolites can also influence immune-cell development, activity and communication. Certain microbial signals promote regulatory responses that help limit excessive inflammation, while others support protective immune mechanisms. Microbes do not always have beneficial effects. Some can trigger inflammation or contribute to disease when they occupy an unsuitable environment or interact with a vulnerable host. The outcome depends on the microbial species, its activity and the condition of the individual. The findings are helping researchers understand why the same broad microbial ecosystem can be associated with health in one context and disease in another .Thus, immune health is not simply a matter of having more Microbes or maximizing bacterial diversity. It involves maintaining appropriate relationships between microbial communities and the host. (Shapiro *et al*. 2026).

From Gut to Brain: A Two way Conversation

One of the most fascinating developments in microbiome research is the study of the gut brain axis. This term describes the communication network connecting the digestive system and the brain through neural, hormonal, immune and metabolic pathways. The intestine contains an extensive nervous system known as the enteric nervous system. It regulates many digestive activities and communicates with the central nervous system through several pathways, including the vagus nerve. Specialized intestinal cells detect chemical signals and release substances that can influence nerve activity. Microbes may contribute to this communication by producing metabolites that interact with intestinal cells, immune pathways and sensory nerves. These signals can help convey information about the intestinal environment to the brain. The relationship also works in the opposite direction. Stress and other brain-related responses can change intestinal movement, secretion and the local environment in which Microbes live. Recent findings have attracted interest in the possible relationships between the microbiome, stress, mood and neurological conditions. However, animal experiments and laboratory findings cannot automatically be applied to humans. The gut microbiome is one component of a much larger physiological network, and it would be inaccurate to claim that particular bacteria directly determine personality or mental health (Ohara and Hsiao, 2025). The gut brain axis nevertheless illustrates how microbial activity may influence processes occurring far beyond the intestine.

Microbial metabolites: Chemical messengers across the body

Microbes influence the body through the substances they produce. The substances, known as microbial metabolites, act as chemical messengers between the intestinal ecosystem and human tissues. SCFAs are one important group. Other examples include modified bile acids and metabolites derived from the amino acid tryptophan. The compounds can interact with receptors, immune pathways and metabolic processes in different tissues. Bile acids are produced by the liver and subsequently modified by intestinal microbes. The resulting molecules participate in signaling pathways involved in metabolism and the regulation of physiological functions. Tryptophan derived microbial metabolites are also receiving attention as some interact with pathways involved in intestinal barrier function and immune responses. Studies brought together research on microbial metabolites as messengers between the intestine and organs including the brain, liver, heart, kidneys, lungs, skin and pancreas. It emphasize that the effects of the molecules vary according to diet, host characters and disease conditions (Feng *et al*., 2026). The emerging fields suggest that microbes may influence distant organs through a network of chemical signals. Identifying a metabolite and/or demonstrating an association does not automatically establish that it causes a particular physiological outcome in humans.

Microbes, diet and metabolic health

The relationship between diet, microbes and human physiology is receiving increasing scientific attention. Dietary patterns influence the substances available to gut microbes, while microbial metabolism change the chemical environment encountered by the host. The researchers have identified microbial strains associated with dietary patterns and health markers, including measures related to cardio metabolic health. The analyses examined how microbial communities changed during dietary interventions (Asnicar *et al*., 2026).

The scale of the study is very important as it demonstrates the potential value of studying microbiomes across large populations rather than relying exclusively on small experimental groups. The authors emphasize that such associations do not, by themselves, establish cause and effect. A microbial strain associated with a favorable health marker may contribute to the outcome, respond to another factor or simply coexist with other concerned changes in diet and lifestyle. The researchers report associations between the metabolites and body fat measures in a human cohort. They also found that particular metabolites, including 4-hydroxyphenylacetic acid, protect male mice against high fat diet induced obesity through mechanisms involving

intestinal immunity and lipid uptake. The animal findings provide possible explanations for how microbial metabolites may influence metabolism, but they do not establish that taking such compounds would prevent obesity in humans (Jiang *et al*., 2025). The studies illustrate an important direction in modern physiology: understanding health may require examining not only what people eat, but also how their microbial communities process the food.

When the microbial ecosystem is disturbed

A healthy microbial community is not defined by a single universal composition. Microbiomes differ among individuals, and their characters are influenced by age, diet, medication, environment and other factors. When microbial composition or function changes in ways associated with an unhealthy state, the term dysbiosis is used. Changes have been reported in several conditions, including intestinal inflammation and metabolic disorders. Antibiotics provide a familiar example of how the microbial ecosystem can bring change. Although the medicines are essential for treating bacterial infections, they also affect susceptible beneficial bacteria. In some circumstances, the disruption creates opportunities for harmful organisms to multiply. The researchers have reported associations between reduced levels of certain metabolites and the depletion of obligate anaerobic bacteria, including changes observed following antibiotic exposure (Kain *et al*., 2026).The research contribute to less invasive ways of assessing microbial function. The findings do not yet mean that a blood test can comprehensively diagnose every microbiome disturbance and/or replace established clinical investigations. An important scientific challenge remains: determining whether microbial changes contribute to disease, result from disease or participate in a two way relationship with the host.

Psychobiotics and Mental Health: The Gut brain Connection

They are a promising class of probiotics that support mental health by influencing the gut microbiota brain axis. Kamal *et al*. (2025) reviewed their potential role in managing anxiety, mood disorders, and cognitive problems. Psychobiotics may improve psychological wellbeing by regulating the hypothalamic pituitary adrenal axis, modulating immune responses, and producing neurotransmitters, neurohormones, and SCFAs. They have discussed evidence from human and animal studies, various bacterial strains, and commercially available formulations. The mechanisms of action remain incompletely understood. Further research is needed to establish their efficacy, safety, and long term benefits for mental health.

Future prospects

The scientists are investigating microbial metabolites, dietary interventions, prebiotics, probiotics synbiotics and psychobiotics, and carefully select microbial communities as possible ways to influence physiological processes. Future approaches may move beyond simply identifying which bacterial strains are present. They may examine what microbes are doing, which biomolecules they produce and how the molecules affect the host. Advanced sequencing, metabolomics and computational analysis are helping scientists investigate the interactions in greater detail. Large population studies identify patterns associated with health, while lab experiments and clinical trials test whether those patterns have meaningful biological effects. Personalized approaches are being explored as two people consuming similar diets may have different microbial communities and metabolic responses. Personalized microbiome recommendations require stronger evidence demonstrating which interventions work, for whom and under what circumstances. It is equally important to distinguish promising research from established medical practice. A finding in mice, a lab model and/or an observational human study is not equivalent to a proven treatment. Well-designed clinical trials and careful safety assessments remain essential.

Conclusion

Microbes are more than microscopic inhabitants of the human body. Through their metabolic activities and interactions with human cells, they participate in a complex network connecting digestion, immunity, metabolism and communication between organs. Research has expanded our understanding of the relationships, particularly by examining microbial metabolites, large population datasets and the gut brain axis. Researchers are learning that microbial effects depend on the surrounding biological environment and can't always be classified as beneficial and/or harmful in isolation. The concept of microbes as hidden physiologists offers a broader perspective on human health. It reminds us that the body's functioning emerges not only from the activities of human cells and organs, but also from their interactions with microscopic partners. Understanding such relationships open new avenues for medical research while helping us appreciate the intricate ecosystem which exists within human body.

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Volume: 06 Issue No: 10

SOME ECO-FRIENDLY INSECT CONTROL METHODS FOR AGRICULTURAL, HORTICULTURAL AND FOREST ECOSYSTEMS OF SIVAGANGAI DISTRICT, TAMIL NADU

Article ID: AG-VO6-I10-76

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Abstract

Sivagangai's rice-dominated intensive system and semi-arid climate make insect pest management one of the most immediate production risks farmers' face. Yet the barrier to adoption of eco-friendly insect control in this district is not a lack of technology but a mismatch between method options and farmers' resource endowments. Drawing on the Tamil Nadu Agricultural University (TNAU) catalogue of biological control products and field validation data, the Tamil Nadu Horticulture Department's bio-pesticide production and subsidy framework, and Indian Council of Forestry Research and Education (ICFRE) research on forest tree pest management, this article screens and recommends insect control methods that farmers can adopt directly, organized across three ecosystem levels: agricultural, horticultural and forest. Core recommendations include yellow sticky traps and light traps in rice fields, use of locally available bio-pesticides (neem oil, *Metarhizium anisopliae*), release of biological control agents in horticultural crops (*Chrysoperla*, *Trichogramma*), and combinations of natural-enemy conservation and mechanical control for forestry boundary species. What these methods share is that they do not require farmers to abandon existing farming systems, and their cash outlay can be reduced through existing subsidy channels.

1. Introduction

Insect pest management in Sivagangai faces a structural dilemma: the availability and subsidy system for chemical pesticides is mature, while the promotion of eco-friendly

alternatives depends on scattered technical training and limited subsidy coverage. For smallholders under debt pressure, the precondition for choosing an ecological method is not "whether it works" but "whether it is easy to obtain, easy to operate, and does not add extra risk.

Tamil Nadu's public supply system offers part of the answer to this precondition. The state has 22 biological control laboratories and 2 Integrated Pest Management centres, which in 2024–25 produced and distributed more than 430,000 kg of *Trichoderma viride*, 600,000 kg of *Pseudomonas fluorescens*, 23,117 cc of *Trichogramma chilonis*, 10,417 kg of *Metarhizium anisopliae* and 7,350 litres of Nuclear Polyhedrosis Virus (NPV). The TNAU Department of Agricultural Entomology's biological control laboratory sells natural enemies directly to farmers *Chrysoperla* eggs, Australian ladybird beetle, *Trichogramma* and *Bracon* at transparent prices. Tamil Nadu's agricultural policy also provides a subsidy for distribution of biological control agents at ₹200 per acre or 50% of cost, whichever is lower.

The question is whether Sivagangai farmers know these resources exist, and whether they match the actual pest spectrum in their fields. This article proceeds across three ecosystem levels, prioritizing within each those methods that have field validation data in Tamil Nadu or connect directly to existing subsidy/extension channels.

2. Agricultural Ecosystem: Insect Control in Rice Fields

2.1 Brown Planthopper: From "Spraying" to "Managing Ecology"

The brown planthopper (BPH; "Pugaiyan" in Tamil) is one of the most destructive pests in Sivagangai's rice belt, capable of causing "hopper burn" within a short period and yield losses of up to 60%. The dilemma of chemical control is that excessive use of urea and certain chemical pesticides actually stimulates BPH egg-laying and reduces natural enemy populations, creating a vicious cycle of "the more you spray, the more you get."

TNAU's recommended eco-friendly management package has clear farmer operability. First, planting resistant/tolerant varieties (ADT 36, Co 46, Co 42, IR 36, Aruna) is a zero-extra-cost foundational measure. Second, maintaining a 30 cm "rogue spacing" every 2.5 m reduces field humidity and pest density. Third, intermittent draining directly disrupts the BPH's breeding micro-environment above the water surface. Fourth, the wolf spider is an important natural enemy of BPH, and planting *Azolla* provides habitat and breeding sites for wolf spiders, strengthening natural control.

When pest density exceeds the economic threshold, TNAU's recommended chemical options also include eco-friendly alternatives: neem oil 3% @ 15 litres/ha, or 25 kg neem seed kernel powder dissolved in 600 litres water/ha. The key advantage of this option is that neem formulations are eligible for partial cost compensation under Tamil Nadu's bio-pesticide subsidy framework.

2.2 Yellow Traps and Light Traps: Low-Cost Monitoring and Suppression Tools

For the various planthoppers and leafhoppers in rice fields, yellow sticky traps and light traps are the lowest-threshold interventions. TNAU's pest forecasts show that sucking pests (aphid, leaf miner, mealybug) continue to pose threats in several Tamil Nadu districts (including Cuddalore, Villupuram). Although Sivagangai-specific pest data are limited, hopper pressure in semi-arid rice areas is widespread.

Yellow traps require no electricity or special equipment; farmers can deploy them at 20–30 per acre at very low cost. Light traps (5 per acre, operated 7–9 pm) can simultaneously monitor nocturnal pest population dynamics. The core value of these tools is not "eradication" but providing farmers with a visual signal of pest density, enabling intervention decisions at the right time rather than calendar-based blind spraying.

2.3 Local Availability of Bio-Pesticides

Tamil Nadu's public biological control laboratory system enables Sivagangai farmers to obtain quality-controlled bio-pesticides at low cost. *Metarhizium anisopliae* (green muscardine fungus) and *Beauveria bassiana* (white muscardine fungus) are two fungal formulations widely produced and recommended in Tamil Nadu for multiple pests. For leafhopper and BPH nymphs in rice fields, soil application or foliar spray of *Metarhizium* can provide effective population suppression under high-humidity conditions.

The practical path for farmers to obtain these products is: inquire at the block-level agricultural extension office about the nearest biological control laboratory distribution point, or contact the TNAU Coimbatore biological control laboratory directly (phone 0422-6611214) for mail order and bulk pricing. Tamil Nadu's subsidy rules mean that if farmers purchase through agricultural department channels, actual cash outlay can fall below ₹100 per acre.

3. Horticultural Ecosystem: Insect Control in Chilli, Cashew and Homestead Crops

3.1 Chilli Thrips: A Validated Ecological Module

Chilli is Sivagangai's main horticultural crop (about 4,709 ha), and thrips is one of its

most economically destructive pests. The chilli thrips integrated management module validated by TNAU at multiple Tamil Nadu locations provides a replicable template: seed treatment with thiamethoxam 30% FS (7.0 g/kg seed); three rows of maize or sorghum planted on field boundaries as barrier crops; intercropping with cluster bean at 6:1; 50 yellow sticky traps per hectare (30–60 cm above ground); and when pest density reaches the economic threshold (5 thrips per leaf), use selective insecticides such as fipronil, dimethoate, thiacloprid or cyantraniliprole.

The ecological logic of this module is that barrier and intercrop species provide habitat and alternative food sources for natural enemies, yellow traps directly suppress adult populations, and selective insecticides are used only when thresholds are breached. For Sivagangai chilli growers, the costliest components are seed treatment and selective insecticides, but barrier crops (maize/sorghum) and intercrop (cluster bean) have very low seed costs, and cluster bean itself can be harvested as a pulse.

3.2 Direct Release of Biological Control Agents

Two natural enemy products sold by the TNAU biological control laboratory have direct application value in horticultural settings. *Chrysoperla* (green lacewing) eggs are sold at ₹450 per 1,000 eggs, with a recommended release of 1,000 eggs per hectare, targeting whiteflies, mealybugs, thrips and other sucking pests. The Australian ladybird beetle is sold at ₹225 per 100 beetles, specifically for mealybug control, with a recommended release of 10–20 per tree. *Trichogramma* egg parasitoids are sold at ₹75 per cc, with a recommended release of 5 cc per hectare, targeting fruit borers, stem borers and leaf rollers.

The practical significance of these products for Sivagangai horticultural farmers is that release operations are simple (hanging *Chrysoperla* egg cards, placing *Trichogramma* egg cards), require no spray equipment, and release timing can be determined in conjunction with field monitoring. For mealybug problems on homestead fruit trees (mango, banana, tamarind), Australian ladybird release is particularly suitable—a rate of 10 per tree means a five-tree homestead needs only 50 beetles, at a cost of about ₹112.

3.3 Low-Intervention Strategies for Cashew and Homestead Fruit Trees

Cashew covers about 4,557 ha in Sivagangai, with relatively lower pest pressure than chilli, though mealybugs and stem borers occur occasionally. For cashew and homestead fruit trees, the core of a minimum-intervention strategy is "sanitation management + natural enemy

conservation": regularly remove and destroy severely infested branches, avoid excessive nitrogen application (excess nitrogen aggravates mealybug and aphid problems), and retain non-crop vegetation on field boundaries as natural enemy refuges.

Tamil Nadu's Paramparagat Krishi Vikas Yojana (PKVY) organic cluster framework offers a certification pathway for interested horticultural farmers, but the yield risk during the conversion period means a more pragmatic approach is "reduce highly toxic pesticides first, then consider certification." For chilli and cashew, this means prioritizing neem formulations and bio-pesticides over broad-spectrum insecticides, and applying for certification only once the management system has stabilized.

4. Forest Ecosystem: Pest Management for Boundary Trees and Catchment Vegetation

4.1 Pest Awareness for Agroforestry Boundary Species

Sivagangai's forestry dimension is mainly expressed in field-boundary planting and catchment vegetation, not commercial forest management. This means the goal of pest management is not "eradicate pests to protect yield" but "maintain tree health to sustain ecological functions (windbreak, nitrogen fixation, shade)."

The ICFRE Institute of Forest Genetics and Tree Breeding (Coimbatore) has conducted systematic research on pest problems of major Tamil Nadu tree species (including *Casuarina*, Teak, *Acacia*, *Albizia*, Tamarind, Neem, *Pongamia*) and developed integrated management methods. The institute has also developed a "pest calendar" reflecting the occurrence timing and severity of major pests in nurseries, trees outside forests and medicinal plants a tool that can directly help Sivagangai farmers judge when to pay attention to boundary tree pest situations.

4.2 Eco-Friendly Pest Control for *Casuarina*

Casuarina is a common species in Tamil Nadu agroforestry boundary planting and a drought-tolerant timber species that performs well under Sivagangai's semi-arid conditions. Its key pests include the stem borer (*Indarbela quadrinotata*), mealybug (*Dysmicoccus brevipes*) and termites.

For the stem borer, the combined methods recommended by ICFRE/IWST (The Institute of Wood Science and Technology) include mechanical control (scraping loose bark to prevent adult oviposition, removing and burning severely infested branches) and light trapping (deployed during the May–June adult emergence period)—both zero-chemical-input measures. Where necessary, injecting kerosene into borer holes (once each in September–October and January–

February) is a low-cost traditional method. For mealybug, releasing the Australian ladybird (*Cryptolaemus montrouzieri*) at 10 per plant is an eco-friendly option, consistent with the TNAU biological control laboratory's ladybird product.

More notably, Tamil Nadu research has found that some *Casuarina equisetifolia* provenances show high levels of tolerance to the stem borer, offering the possibility of "genetic resistance" through seed-source selection. For Sivagangai farmers, this means prioritizing seedlings from resistant provenances when establishing new boundary plantings, rather than arbitrary nursery sources.

4.3 Nursery Hygiene as the First Line of Defence

For any farmer raising seedlings at home or by the field, nursery hygiene is the easiest-to-implement and most durable pest prevention measure. ICFRE research explicitly lists "good nursery hygiene" alongside "resistant clone selection" as foundations of integrated management. Specific practices include: using clean potting media (avoiding soil from known pest outbreak areas), regularly inspecting and removing infested seedlings, and avoiding excessive density to reduce mealybug and aphid transmission. Tamil Nadu's biological control laboratory system also provides *Trichoderma* and *Pseudomonas* products for the nursery stage; while these mainly target diseases, healthy roots and seedlings inherently enhance pest tolerance.

5. Screening Logic for Method Adoption and Policy Linkages

5.1 Layering by Farmer Resource Endowment

Zero cash outlay layer: resistant variety selection (rice ADT 36/Co 46 etc.), field sanitation (removing infested branches), intermittent draining, boundary crop planting (maize/sorghum barriers), natural enemy conservation (retaining boundary vegetation, avoiding excessive nitrogen). This layer suits all farmers, especially marginal farmers unable to bear additional costs.

Low cash outlay layer: yellow traps and light traps (low material cost, self-made or locally purchased), neem oil/neem seed kernel extract (local materials or low-cost commercial formulations), TNAU biological control laboratory natural enemy products (*Chrysoperla* ₹450/1,000; *Trichogramma* ₹75/cc; ladybird ₹225/100). Single applications typically cost in the hundreds of rupees and can be further reduced through the biological control subsidy (₹200 per acre or 50% of cost).

Policy linkage layer: apply through block-level agricultural extension offices for subsidized procurement of biological control agents; obtain technical training on the chilli thrips management module through horticulture departments; apply for organic certification under the PKVY cluster framework (noting conversion-period risks).

5.2 Practical Pathways for Information Access

Three reliable channels for Sivagangai farmers to access these resources and information are: first, the block-level agricultural extension office—responsible for distribution and subsidy registration of biological control agents; second, the TNAU Coimbatore biological control laboratory (0422-6611214)—direct sales of natural enemy products and technical advice; third, TNAU's monthly pest forecast reports—communicated to block level through district agricultural departments, with farmers able to request crop-specific pest alerts from extension staff.

One often-overlooked but crucial fact is that Tamil Nadu's biological control laboratory network has no facility in Sivagangai. The nearest laboratories are in Madurai (Vinayagapuram) and Pudukottai (Annavasal). This means the logistics cost of obtaining natural enemy products must be factored in—bulk procurement (jointly by multiple households) or centralized ordering through block extension offices is the more economical approach.

Conclusion

Eco-friendly insect control in Sivagangai does not require waiting for new technology. Resistant varieties, draining management and neem formulations in rice fields; the barrier crop–yellow trap–threshold spraying module in chilli; and mechanical control plus ladybird release for forestry boundary trees have all formed operable technology packages within Tamil Nadu's public research and extension system. TNAU's biological control laboratory and Tamil Nadu's subsidy framework make the economic threshold of these methods far lower than farmers typically perceive. The real obstacle is information asymmetry and distribution distance. A rice farmer in Sivagangai taluk may not know that ADT 36 is more resistant to BPH than the variety currently used; a chilli grower in Tiruppathur may not know that three rows of maize on the boundary can reduce thrips invasion; a farmer managing boundary *Casuarina* in Ilaiyangudi may not know that bark scraping combined with light trapping can replace most chemical spraying.

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Volume: 06 Issue No: 10

SEASONAL OUTBREAKS OF MILLIPEDES DURING AND AFTER THE RAINY SEASON

Article ID: AG-VO6-I10-77

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Introduction

Have you ever noticed hundreds or even thousands of millipedes crawling across the ground, garden paths, walls, or the floors of houses during the rainy season? In some places, these small, many-legged creatures suddenly appear in enormous numbers, creating concern among farmers, gardeners, and residents. Areas that were almost free of millipedes during the summer may become crowded with them after a few heavy showers. Although such mass appearances may seem unusual, they are closely connected to the relationship between millipedes and their environment. Rainfall, soil moisture, humidity, temperature, food availability, and the natural behaviour of these animals all play important roles in determining when millipedes become abundant and visible.

Millipedes: The hidden workers of the soil

Millipedes are terrestrial arthropods belonging to the class Diplopoda. They are easily recognised by their elongated, segmented bodies and numerous short legs. Despite their worm-like appearance, they are not worms or insects. Most millipedes are slow-moving animals that live in moist places, such as beneath fallen leaves, stones, decaying logs, and within the soil. Millipedes play an important role in maintaining healthy ecosystems. Most species feed on dead and decaying plant material, including fallen leaves, rotting wood, and other organic debris. By breaking this material into smaller fragments, they help microorganisms decompose it more efficiently. This process contributes to nutrient cycling, organic matter breakdown, and soil formation. Therefore, millipedes are generally beneficial components of natural ecosystems and agricultural soils.

However, when they occur in unusually large numbers and move into houses, roads, gardens, or cultivated areas, they can become a temporary nuisance.

Why does the rainy season favour millipedes?

Moisture is essential for survival

One of the most important factors influencing millipede activity is moisture. Millipedes are vulnerable to water loss through their body surfaces, and prolonged exposure to hot, dry conditions can lead to desiccation. Consequently, they usually seek shelter in moist microhabitats during dry weather. During the rainy season, rainfall increases soil moisture and relative humidity. The soil beneath leaf litter, stones and decaying vegetation remains moist for longer periods. These conditions allow millipedes to remain active for extended periods without losing excessive water.

Abundant food becomes available

The rainy season also provides favorable feeding conditions. Rain promotes plant growth, increases the production of leaf litter in many habitats, and encourages the growth of fungi and other decomposer organisms. Moist fallen leaves and decaying plant material provide suitable food for many millipede species. Under humid conditions, decomposition proceeds actively, making organic matter a valuable resource for these detritus-feeding animals. Gardens, plantations, forests, agricultural fields, and areas with accumulated leaf litter can therefore become favourable habitats. Where suitable shelter and food are plentiful, local millipede populations may survive and persist in considerable numbers.

Suitable conditions support growth and development

Temperature and moisture influence the activity, growth, moulting, and reproduction of millipedes, although the precise requirements differ among species. During dry and hot weather, many millipedes reduce their activity or remain hidden in the soil and other sheltered places. When rainfall returns, favourable moisture conditions may allow them to resume feeding and movement. In some species, eggs and young individuals develop in moist soil or organic matter. Suitable environmental conditions can improve survival during these stages.An apparent outbreak does not necessarily mean that the population has suddenly reproduced. It may instead reflect the increased activity or movement of individuals that were already present in the habitat.

Heavy rainfall: A trigger for mass movement

An important reason for the sudden appearance of millipedes is the direct effect of heavy

rainfall on their habitat. Millipedes generally require moisture, but excessive water can be just as disruptive as dry conditions. When intense or continuous rainfall saturates the soil, fills small spaces with water, or floods their usual shelters, millipedes may be forced to leave these locations. They may then move towards relatively elevated or less waterlogged ground, including roadsides, pathways, building foundations, walls, and house interiors. Because many individuals may respond to the same environmental disturbance at approximately the same time, their movement can create the impression of a sudden population explosion. Extension specialists have documented this phenomenon, noting that heavy rain can flush millipedes out of their normal outdoor habitats and lead to mass appearances around buildings. Excessively dry conditions can also trigger movement as millipedes search for more suitable moisture levels. Thus, both excessive rainfall and drought can cause millipedes to move out of their usual shelters, although the direction and outcome of their movement depend on local conditions.

Why are outbreaks often noticed after the rainy season?

Millipede outbreaks may occur during the monsoon or shortly afterwards. The timing depends on the species, local climate, rainfall pattern, habitat and life cycle. During the rainy season, moist soil and abundant organic matter may support increased activity and survival. After heavy showers, individuals may become more visible as they move away from flooded or disturbed shelters. In some habitats, the effects of the monsoon persist even after rainfall decreases (Rannavre *et al*., 2024). Soil moisture may remain high, temperatures may become more moderate and decomposing vegetation may continue to provide food. These conditions can support millipede activity during the post-monsoon period. Seasonal activity does not always correspond directly to population growth. A large number of millipedes seen on a road or near a house may represent a temporary concentration of individuals from the surrounding area rather than a newly developed population.

Are millipede outbreaks harmful?

In most situations, millipedes are not dangerous to humans. They do not bite or sting and most species feed primarily on decaying organic material rather than living plants. Nevertheless, large aggregations can cause practical problems. Millipedes may enter houses, accumulate around doors and windows, produce unpleasant odours when disturbed or crushed, and become a nuisance in gardens and public spaces. Some species may occasionally feed on tender seedlings or other living plant material. Their presence should not automatically be interpreted as a sign of

poor sanitation or a serious agricultural pest outbreak. In many cases, it reflects seasonal changes in moisture and habitat conditions.

Managing millipede outbreaks in an eco-friendly way

The most effective approach is to reduce the conditions that encourage millipedes to gather near buildings while protecting their beneficial role in the ecosystem.

Reduce excessive moisture near buildings: Repair leaking taps and pipes, improve drainage, and prevent water from accumulating around foundations.

Manage leaf litter and organic debris: Remove excessive accumulations of decaying leaves, rotting wood, and other debris immediately next to entrances and walls. Organic matter can be retained in suitable garden or composting areas away from buildings.

Seal entry points: Close gaps around doors, windows, pipes, and foundations to reduce the entry of wandering millipedes.

Use physical removal: Sweep or collect millipedes and move them to suitable outdoor habitats when practical. Avoid crushing large numbers indoors, as some species release irritating or unpleasant-smelling defensive secretions.

Avoid unnecessary pesticide use: Broad pesticide applications may harm beneficial soil organisms and other non-target animals. Chemical control should be considered only when genuinely necessary and in accordance with local recommendations.These measures are generally more useful for reducing nuisance around buildings than attempting to eliminate every millipede from the surrounding environment.

Conclusion: The monsoon reveals a hidden world

The seasonal outbreak of millipedes illustrates how closely animal life is connected to weather and habitat conditions. Rainfall increases soil moisture, supports the availability of decaying organic matter, and creates favourable conditions for many millipede species. At the same time, excessive rain can flood their shelters and drive them into open spaces, where their presence becomes especially noticeable. Therefore, the large numbers observed during or after the rainy season may result from a combination of increased activity, favorable survival conditions, Rather than viewing every millipede outbreak as a biological disaster, we should recognise these animals as important participants in the natural process of decomposition and nutrient recycling. With a better understanding of their ecology and some simple habitat-

management practices, it is possible to minimise their nuisance while appreciating the valuable role they play in maintaining healthy soils.

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Volume: 06 Issue No: 10

FEEDING MANAGEMENT OF PET BIRDS

Article ID: AG-VO6-I10-78

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Introduction

Nutritional requirements in pet birds vary significantly across their different stages of life. Most of the pet birds are altricial, born naked and blind, featherless, and entirely dependent on parental care for several weeks, with the exact duration varying by species. During the intensive rearing phase, parent birds require a substantially increased caloric and nutrient intake to meet both their own maintenance needs and the rapid metabolic demands of their offspring. Supplemental soft foods, rearing formulations, seeding grasses, fresh produce, and insect larvae of certain insectivorous or omnivorous species are critical to meet the demands of feeding. During the breeding season, hens experience greater total energy expenditure alongside markedly increased requirements for bioavailable protein, essential fatty acids, vitamins, and minerals. Egg production imposes a severe physiological drain on body reserves, frequently predisposing the hen to a negative calcium balance if dietary intake is inadequate. Although cuttlefish bone is a traditional calcium source, its absorption efficiency is very limited. Soluble calcium formulations offer superior bioavailability, particularly when rapid therapeutic restoration is required. Additionally, strategic water-soluble multivitamin supplementation via drinking water helps prevent subclinical deficiencies during peak production. Besides, the maintenance requirements of adult birds fluctuate based on physical activity, environmental ambient temperature, and physiological stress. Especially, during the moult, protein, sulphur and amino acid requirements rise significantly to support the synthesis and structural integrity of new plumage.

Components of Pet Bird Feed

To maintain optimal physiological condition, pet birds must be fed with varied diet comprising quality seed blends, sprouted grains, fresh produce, commercial pelleted feeds or crumbles, mineral supplements, and species-appropriate animal proteins (e.g., insect larvae or cooked egg). In addition to dietary nutrition, mineral blocks, natural chalk blocks, and fresh, non-toxic browse (budding branches) serve an important mechanical function by facilitating natural beak wear and helping prevent beak overgrowth. Aviculturists must regularly inspect stock for both beak hypertrophy and overgrown nails, which are common issues in captive pet bird management.

Fruits and vegetables*:* This forms a very important part of the pet bird's diet. Dark green or yellow vegetables should be offered daily. Fruits and vegetables such as apples, pumpkin, grapes, carrot, parsley, broccoli, mango, sweet potato, squash, and spinach can be fed in small quantities. The fruits and vegetables should be fed in raw form as cooking may sometime take away the vital nutrients.

Sprouted mixed grains: Mix a few types of ingredients from each subcategory.

- **Grains (50%):** e.g., wheat, barley, oats, or millet
- **Legumes (25%):** e.g., peas, mung beans, or lentils
- **Herb Seeds (12.5%):** e.g., clover or alfalfa
- **Oilseeds (12.5%):** e.g., sunflower or sesame

For example, 2 or more herb seeds, 2 or more grains, 2or more oil seeds and 2 or more legumes. The diversity and balance of seeds, grains and legumes are complementary so that by feeding a variety, the blend alone is capable of providing the nutrients required by the birds. After mixing strain the seeds and put it in a wet cloth sack and keep it for another 6 – 8 hours while frequently rinsing and washing the contents. After the appearance of sprouting tails, the seeds can now be stored in refrigerator up to 5 days.

Vegetables: For optimum health, the birds can be fed with finely chopped vegetables daily like asparagus, beets, carrots, green beans, pumpkin, sweet potato and tomato etc.

Fruits: Feed fruit in small amounts and less often than vegetables. Do not used cooked or canned fruit and do not include the seeds in fruit. Fruits like apple, banana, berries, dried fruits, grapes, lemon, mango, melons, papaya, peach, pears and pineapple etc. can be fed in little quantities.

Other miscellaneous food items like cuttlebone, dried fruit, dried vegetables, eggs, human baby food, mealworms, nuts, pumpkin seeds can also be fed to the birds.

Unsafe foods for most of the pet birds are avocado, mushrooms, onion, garlic, raw meat and poultry, milk or cheese, potatoes, eggplants, apple seeds or pear, plum, cherry, apricot and peach seeds, chocolate, junk foods etc.

Water: when kept in captivity a fresh supply of clean, quality drinking water should be available at all times to all kind of pet birds. However, birds like budgerigars possess specialized physiological mechanisms to retain water and produce very dry, hard faecal droppings. In fact, they have adapted to living in the desert and they can survive in good health for up to 150 days on seed alone, without a water supply. Some pet birds also like to bathe in water, so a shallow dish containing water should be placed in captive areas in addition to a drinking water trough.

Common Feed Ingredients for Pet Birds

S.no	Pet Birds	Feed ingredients
1	Cockatiels	Seeds, Canary mix, parakeet mix, sunflower, spray millet. Greens: Spinach, alfalfa cubes. Fresh vegetables: Primarily corn, carrots. Fruits: Apples and grapes (often not fond of fruit). Supplements: Salt, cuttlebone, mineral block, oyster shell, cheese, monkey biscuit, and vitamins.
2	Cockatoos	Sunflower seeds, monkey biscuits, corn on the cob, apples, oranges, cheese, spinach, carrots, legumes (soybeans and lentils), cooked eggs (especially hardboiled shell), calcium supplements (such as calcium lactate, gluconate carbonate), oyster shells, cuttlebone, supplemental vitamins
3	Conures	Seeds plus "bread mixture" made of whole wheat bread crumbled, endive, carrots, plus vitamin supplements
4	Finches	Small finch mix, millet, thistle, canary, rape, pound cake. Insectivorous (Melbas, Auroras, Violet-ears, Cordon Bleus, etc.): Add a couple of mealworms daily (too many meal worms rots, spinach. Protein supplement: Monkey biscuit, egg, cheese. Calcium supplement: Cuttlebone, oyster shell. Vitamin

		supplement: May want to use during times of stress or molt. Increase amount of soft food available during laying and feeding of young
5	Macaws	Sunflower seeds, monkey biscuits, corn on the cob, apples, oranges, cheese, spinach, carrots, legumes (soybeans and lentils), cooked eggs (especially hardboiled shell), calcium supplements (such as calcium lactate, gluconate carbonate), oyster shells, cuttlebone, supplemental vitamins
6	Parakeets (Budgerigars)	Fifty percent canary seed mix, 5 percent oats, 45 percent mixed millets, greens, monkey biscuit, cuttlebone, small seed sprouts, corn, carrot, and cheese, or as described for canaries
7	Australian Parakeets	Psittacine diet along with wild seedling grasses.
8	Parrots (African Greys and Amazons)	Psittacine diet along with canary and parakeet mix, occasionally oranges, meat, and egg
9	Pigeons and Doves.	Fresh commercial pigeon pellet, beans, peas, and mixed grains plus vitamin/ mineral supplements
10	Raptors (Falcons, Hawks, Other Birds of Prey)	These are flesh eaters and some of the foods commonly fed to these birds include chicken necks, baby chicks, small rodents, their complete internal organs, and a vitamin mineral supplement that includes calcium, vitamin A, D3, and B complex. They start accepting food with talons instead of their beak at about 4 weeks of age.

Feeding Schedule and Methods

Birds in the wild spend at least 1/3 of their day foraging for food. Formulated diet can be available at all times. Natural feeding times in wild birds are about a half an hour after sunrise and again at 5-6 PM in the evening, so these would be good times to offer the fresh vegetables. Always remove any uneaten vegetables or fruit at the next feeding. Providing food exclusively in standard open dishes deprives captive birds of this essential behaviour, frequently leading to chronic boredom, stress, feather-damages, and psychogenic stress to

birds. Hence, foraging toys can be left in the cage throughout the day for snacking and entertainment.

Conclusion

Feeding management in pet birds is critical multifaceted discipline that extends far beyond simply filling a seed dish. A successful nutritional strategy must include all essential nutrients in feed to meet the physiological demands that occur throughout the lifespan of the birds. Hence, integrating nutrition with evidence-based behavioral enrichment will serve as the foundation for optimal bird health, longevity, and overall psychological welfare of pet birds.

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Volume: 06 Issue No: 10

KARST AQUATIC ECOSYSTEMS: HIDDEN WATERS, UNIQUE BIODIVERSITY AND THE ECOLOGY BENEATH THE SURFACE

Article ID: AG-VO6-I10-79

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Abstract

Karst aquatic ecosystems represent distinctive and often overlooked environments where geological processes, groundwater movement and biological communities interact beneath the Earth's surface. Formed primarily in soluble rocks such as limestone and dolomite, karst landscapes develop complex networks of sinkholes, fractures, caves, underground streams, aquifers and springs. These interconnected habitats support diverse microbial communities and specialized aquatic organisms adapted to darkness, limited food availability and distinctive hydrochemical conditions. Unlike surface aquatic ecosystems, many subterranean habitats receive little or no sunlight and depend largely on organic matter transported from the surrounding landscape. Microorganisms play essential roles in carbon transformation, nutrient cycling and the functioning of underground food webs, while specialized crustaceans, molluscs, worms and fishes contribute to the ecological diversity of these environments. Karst aquifers also

provide important freshwater resources and connect surface waters with groundwater-dependent ecosystems. However, their complex drainage networks and rapid groundwater flow can facilitate the movement of agricultural chemicals, sewage, industrial contaminants and pathogens into otherwise inaccessible habitats. Climate variability, excessive groundwater extraction, habitat disturbance and coastal seawater intrusion may further affect their ecological stability. This article explores the formation and ecological structure of karst aquatic ecosystems, subterranean biodiversity, microbial processes, food-web relationships, groundwater connectivity, anchialine habitats, ecosystem services and emerging conservation challenges. It also highlights the application of environmental DNA, microbial community analysis, hydrochemical monitoring and geospatial techniques in understanding these hidden environments. Recognizing karst as an interconnected aquatic system is essential for protecting its unique biodiversity, maintaining groundwater quality and improving the conservation of these ecologically important landscapes.

Key Words: Karst ecosystem; Karst aquifer; Groundwater ecology; Subterranean biodiversity; Stygobionts; Cave ecosystems; Groundwater microbiome; Anchialine habitats; Aquatic conservation; Groundwater pollution.

1. Introduction

Karst ecosystems are unique environments formed by the dissolution of soluble rocks, particularly limestone and dolomite. This geological process creates caves, sinkholes, underground streams, springs and aquifers that support specialised aquatic habitats. Although largely hidden beneath the Earth's surface, these ecosystems play a vital role in groundwater storage, freshwater supply and biodiversity conservation (Culver & Pipan, 2019).

Karst aquatic systems are characterised by interconnected underground channels through which water, nutrients and microorganisms move. Their specialised habitats support diverse organisms, including crustaceans, aquatic worms and microorganisms adapted to darkness and limited food availability. However, rapid water movement and limited natural filtration can make these systems highly vulnerable to pollutants entering from agricultural land, settlements and industrial activities.

Karst ecosystems provide essential services by supplying freshwater and sustaining springs and associated aquatic habitats. Increasing groundwater extraction, land-use changes and contamination threaten their ecological integrity. Integrated monitoring using hydrochemical

analysis, biodiversity surveys, environmental DNA (eDNA) and GIS mapping can improve our understanding and conservation of these fragile environments. Therefore, protecting karst ecosystems is essential for maintaining groundwater quality, aquatic biodiversity and long-term freshwater security.



2. Formation and Hydrogeological Characteristics of Karst Ecosystems

2.1 Geological Formation

Karst ecosystems develop through the gradual dissolution of soluble rocks, particularly limestone and dolomite, by slightly acidic water. Over time, this process creates distinctive landforms such as sinkholes, caves, fissures and underground streams, providing diverse aquatic habitats (Ford & Williams, 2007).

2.2 Groundwater Flow and Storage

Water enters karst systems through rainfall infiltration, sinkholes and surface openings. It moves through interconnected fractures and enlarged underground conduits, allowing rapid transport between surface water and groundwater. This connectivity influences groundwater recharge, contaminant movement and water availability (White, 2002).

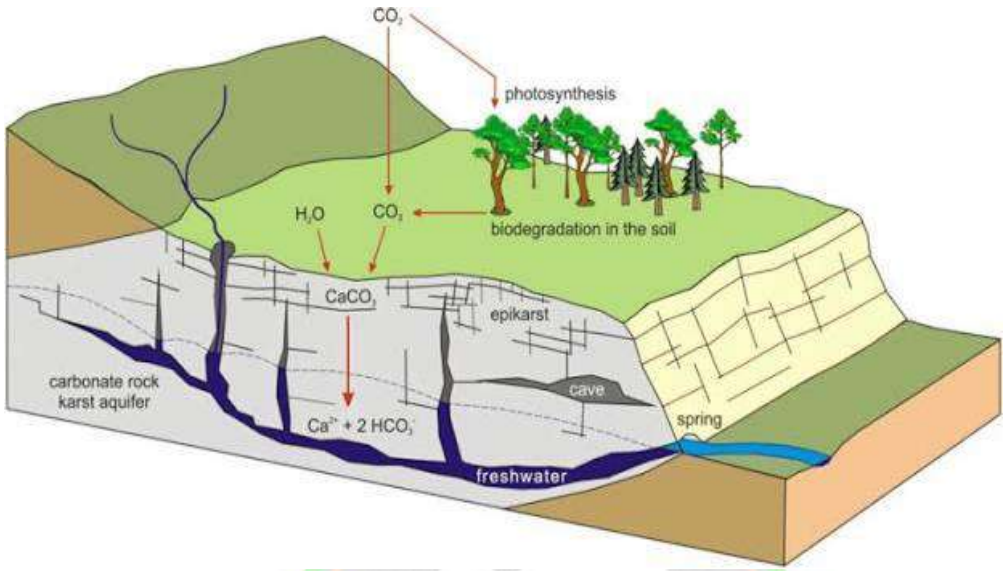
2.3 Major Hydrogeological Components

Karst aquifers consist of recharge zones, underground drainage channels, groundwater storage regions and discharge points such as springs. The interaction between these components determines water movement, residence time and the exchange of nutrients and organic matter within the ecosystem.

2.4 Ecological Significance

The hydrogeological structure of karst systems creates specialised habitats for subterranean aquatic organisms. However, rapid groundwater flow and limited natural filtration can increase their vulnerability to pollutants from agricultural runoff, wastewater and industrial

activities. Understanding these characteristics is essential for groundwater protection and ecosystem conservation.



3. Major Types of Karst Aquatic Ecosystems

3.1 Subterranean Rivers and Streams

Subterranean rivers and streams flow through caves, fractures and underground conduits. They transport water, dissolved nutrients and organic matter, supporting specialised aquatic communities adapted to darkness and limited food availability.

3.2 Karst Springs

Karst springs occur where groundwater emerges naturally at the land surface. They provide freshwater to rivers, wetlands and surrounding communities, while supporting diverse aquatic organisms. Their water quality is strongly influenced by activities occurring within the recharge area.

3.3 Cave Pools and Underground Lakes

Cave pools and underground lakes form in depressions and chambers within karst formations. These habitats often experience low light, limited primary production and relatively stable environmental conditions, supporting specialised microorganisms and subterranean fauna.

3.4 Karst Aquifers

Karst aquifers are underground water-bearing systems developed in soluble rocks. They store and transmit groundwater through fractures, cavities and conduits, making them important freshwater resources.

However, their rapid flow pathways can facilitate the spread of contaminants.

3.5 Anchialine Ecosystems

Anchialine ecosystems are coastal water bodies connected to the sea through underground passages but lacking a direct surface connection. They may contain distinct layers of freshwater, brackish water and seawater, creating specialised habitats for unique aquatic organisms.

These ecosystem types differ in hydrology, water chemistry, habitat structure and biodiversity, making their protection essential for maintaining groundwater resources and ecological diversity (Culver & Pipan, 2019).

4. Biodiversity and Ecological Adaptations in Karst Ecosystems

4.1 Subterranean Aquatic Fauna

Karst waters support specialised organisms, including crustaceans, aquatic worms, molluscs and certain fish species. Many inhabit underground environments where food and light are limited, making them important indicators of subterranean ecosystem health.

4.2 Adaptations to Darkness

Many cave-dwelling organisms exhibit reduced pigmentation, diminished eyes and enhanced sensory structures. These adaptations help them survive in permanent darkness, locate food and navigate through narrow underground passages (Culver & Pipan, 2019).

4.3 Microbial Diversity

Bacteria, archaea and fungi contribute to organic matter decomposition, nutrient cycling and the transformation of dissolved compounds. In some groundwater environments, microbial communities also support food webs through chemosynthesis, where energy is obtained from chemical reactions rather than sunlight.

4.4 Food Webs and Energy Sources

Because photosynthesis is generally absent in deep subterranean habitats, food webs depend largely on organic matter transported from the surface, including leaf litter, soil-derived material and microbial biomass. These energy inputs influence organism abundance and ecosystem functioning.

4.5 Endemism and Conservation Importance

Geographical isolation and specialised habitat conditions can result in species occurring only within particular caves or aquifer systems. Such endemic organisms may be highly

vulnerable to habitat disturbance and groundwater contamination, highlighting the importance of biodiversity surveys and habitat protection.

5. Physicochemical Characteristics of Karst Aquatic Ecosystems

5.1 Water Temperature

Groundwater temperature is generally more stable than surface-water temperature because of the insulating effect of surrounding rock. However, shallow karst aquifers and cave streams may exhibit seasonal variations depending on recharge, groundwater residence time and exchange with surface water. Temperature influences microbial metabolism, dissolved oxygen solubility and aquatic organism activity.

5.2 pH and Alkalinity

The dissolution of carbonate rocks, particularly limestone and dolomite, commonly produces neutral to alkaline water. Bicarbonate is often the dominant dissolved inorganic carbon species under these conditions and contributes substantially to alkalinity. These chemical properties influence carbonate equilibria, nutrient availability and the mobility of certain contaminants.

5.3 Dissolved Oxygen

Dissolved oxygen concentrations depend on groundwater recharge, water turbulence, atmospheric exchange and microbial consumption of oxygen during organic matter decomposition. Rapidly flowing, well-aerated waters may maintain relatively high oxygen concentrations, whereas poorly ventilated or organic-rich groundwater zones can develop oxygen-depleted conditions that affect aquatic communities and biogeochemical processes.

5.4 Hardness and Major Ions

The dissolution of limestone and dolomite releases calcium and magnesium ions, frequently resulting in moderate to high water hardness. Calcium, magnesium and bicarbonate are therefore important indicators of carbonate-rock interaction. Their concentrations vary with lithology, groundwater residence time, dilution and mixing with other water sources.

5.5 Nutrients and Dissolved Organic Carbon

Nitrate, ammonium, phosphate and dissolved organic carbon enter karst waters through natural soil processes and surface-derived inputs. Agricultural fertilisers, sewage and livestock waste can increase nutrient loading, potentially altering microbial activity and groundwater quality.

Because some karst systems transmit recharge rapidly, nutrient concentrations may change considerably following rainfall events.

5.6 Hydrochemical Assessment

Systematic monitoring of temperature, pH, electrical conductivity, dissolved oxygen, alkalinity, hardness, major ions and nutrients helps characterise karst-water chemistry and identify potential contamination. Interpreting these parameters alongside rainfall, groundwater levels and flow conditions provides a more reliable assessment of hydrogeological processes and ecosystem health.

6. Ecological Functions and Biogeochemical Processes in Karst Ecosystems

The major ecological functions and biogeochemical processes operating in karst aquatic ecosystems, together with their underlying mechanisms and ecological significance, are summarised in Table 1.

Table 1. Major ecological functions and biogeochemical processes in karst aquatic ecosystems

Ecological process	Principal mechanism	Ecological significance
Organic matter decomposition	Microbial breakdown of soil-derived and surface-transported organic matter	Supplies energy and nutrients to subterranean food webs
Carbon cycling	Carbonate dissolution, carbon dioxide exchange and microbial respiration	Regulates carbon transfer among rocks, groundwater and the atmosphere
Nitrogen transformation	Ammonification, nitrification and denitrification	Influences nitrogen availability and groundwater nitrate concentrations
Phosphorus cycling	Mineral interactions, sediment retention and organic matter decomposition	Regulates phosphorus transport and availability
Microbial contaminant transformation	Microbial degradation and transformation of susceptible compounds	Contributes to natural attenuation of certain pollutants

Surface–groundwater connectivity	Water and material exchange through fractures, conduits and springs	Links habitats and transfers nutrients, organisms and contaminants

7. Conservation and Sustainable Management of Karst Aquatic Ecosystems

7.1 Recharge Zone Protection

Map groundwater recharge areas and restrict waste disposal, quarrying and high-risk construction near sinkholes and vulnerable infiltration zones.

7.2 Pollution Control

Install effective sewage-treatment systems, inspect septic tanks, control fertiliser application and regularly monitor industrial effluents entering karst drainage pathways.

7.3 Sustainable Groundwater Use

Monitor groundwater levels and spring discharge, establish extraction limits based on aquifer conditions, and reduce pumping during periods of low recharge.

7.4 Biodiversity Conservation

Survey cave-dwelling species, protect sensitive habitats, regulate cave tourism and prevent the introduction of non-native organisms into subterranean waters.

7.5 Community Participation

Conduct local awareness programmes, organise spring-cleaning activities where appropriate, and establish community reporting systems for pollution incidents and illegal dumping.

7.6 Integrated Monitoring

Measure water quality before and after monsoon rainfall, use GIS to map pollution hotspots, and apply eDNA surveys to track sensitive or rare aquatic species.

Conclusion

Karst aquatic ecosystems are ecologically valuable environments that support specialised biodiversity, sustain freshwater resources and regulate important biogeochemical processes. However, their interconnected drainage networks make them vulnerable to pollution, excessive groundwater extraction, land-use changes and climate variability. Protecting recharge zones, controlling contaminant inputs and regulating groundwater use are essential for maintaining their ecological integrity.

Integrating hydrochemical monitoring, GIS mapping, environmental DNA and microbial analysis can improve the assessment and conservation of these complex systems. Effective management also requires long-term monitoring, scientific research, appropriate environmental policies and community participation. Recognising karst ecosystems as interconnected ecological systems rather than merely underground water reservoirs is crucial for safeguarding freshwater security, conserving unique biodiversity and ensuring their resilience for future generations.

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Volume: 06 Issue No: 10

PHYSIOLOGICAL, BIOCHEMICAL AND MOLECULAR BASIS OF SALT TOLERANCE IN RICE: IMPLICATIONS FOR THE CAUVERY DELTA REGION OF TAMIL NADU

Article ID: AG-VO6-I10-80

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Abstract

Soil and water salinity are important constraints to sustainable rice production in vulnerable coastal environments. The Cauvery Delta of Tamil Nadu, a major rice-growing region, faces environmental challenges associated with variable freshwater availability, coastal groundwater salinisation, seawater intrusion, and land degradation. However, the extent and severity of salinity vary considerably across locations and seasons. Rice (*Oryza sativa* L.) is sensitive to excessive salt concentrations, which impair water uptake, disrupt ionic homeostasis, induce oxidative stress, and reduce growth and grain yield. Salt tolerance is governed by interacting physiological, biochemical, and molecular mechanisms, including sodium exclusion, potassium retention, osmotic adjustment, antioxidant defence, hormonal regulation, and stress-responsive gene expression. Important molecular components include the Saltol quantitative trait locus, the OsHKT1;5 sodium transporter, sodium/hydrogen exchangers, and transcriptional regulatory networks. Advances in molecular breeding, genomic selection, and genome editing provide opportunities to improve rice adaptation to saline environments. In the Cauvery Delta, these approaches must be combined with site-specific soil assessment, freshwater conservation, appropriate drainage, and sustainable irrigation management. This chapter reviews the physiological, biochemical, and molecular foundations of rice salt tolerance and discusses their application to climate-resilient rice production in the Cauvery Delta region of Tamil Nadu.

Keywords: Rice; salinity stress; Cauvery Delta; Tamil Nadu; ion homeostasis; antioxidant defence; Saltol; molecular breeding; seawater intrusion; sustainable agriculture.

1. Introduction

Rice is a major staple food crop in India and is central to agricultural livelihoods, food security, and rural employment in Tamil Nadu. The Cauvery Delta, encompassing important agricultural areas of Thanjavur, Tiruvarur, Nagapattinam, Mayiladuthurai, and adjoining districts, is particularly important for rice production. Its agricultural productivity depends on the availability of freshwater, suitable soil conditions, effective drainage, and the timely establishment of crops.

Coastal agricultural systems are vulnerable to environmental changes that can alter soil and groundwater quality. Seawater intrusion, excessive groundwater extraction, seasonal water shortages, and inadequate drainage may contribute to salinity problems in susceptible locations. A study by Mohamed Tharik and Vijayaraghavalu (2024) investigated groundwater quality and seawater intrusion across coastal districts of Tamil Nadu, including parts of the Cauvery Delta region (Fig no:1). The findings highlight the importance of monitoring irrigation-water quality and managing groundwater extraction. Research in a coastal village in the Cauvery Delta has also documented the interaction between land degradation, seawater intrusion, and agricultural livelihoods (Pratheepa *et al.,* 2023). Nevertheless, the entire Cauvery Delta should not be considered uniformly saline. Soil salinity varies with distance from the coast, soil properties, groundwater conditions, irrigation practices, and season. Consequently, regional salinity management requires field-level assessment rather than assumptions based solely on geographical location.

Rice is classified as a salt-sensitive crop, although considerable genetic variation exists in its ability to withstand salinity. Excessive salt concentrations reduce the water potential of the soil solution, disturb nutrient uptake, and promote the accumulation of toxic ions. These effects can impair germination, seedling establishment, vegetative growth, flowering, and grain filling (Munns & Tester, 2008). Understanding the physiological, biochemical and molecular mechanisms underlying salt tolerance is essential for developing rice cultivars suited to salt-affected environments. The objectives of this chapter are to review these mechanisms and discuss their relevance to sustainable rice production in the Cauvery Delta of Tamil Nadu.

Source: Tamil Nadu Agricultural University, Agro-Climatic Zone and Cropping Pattern information.

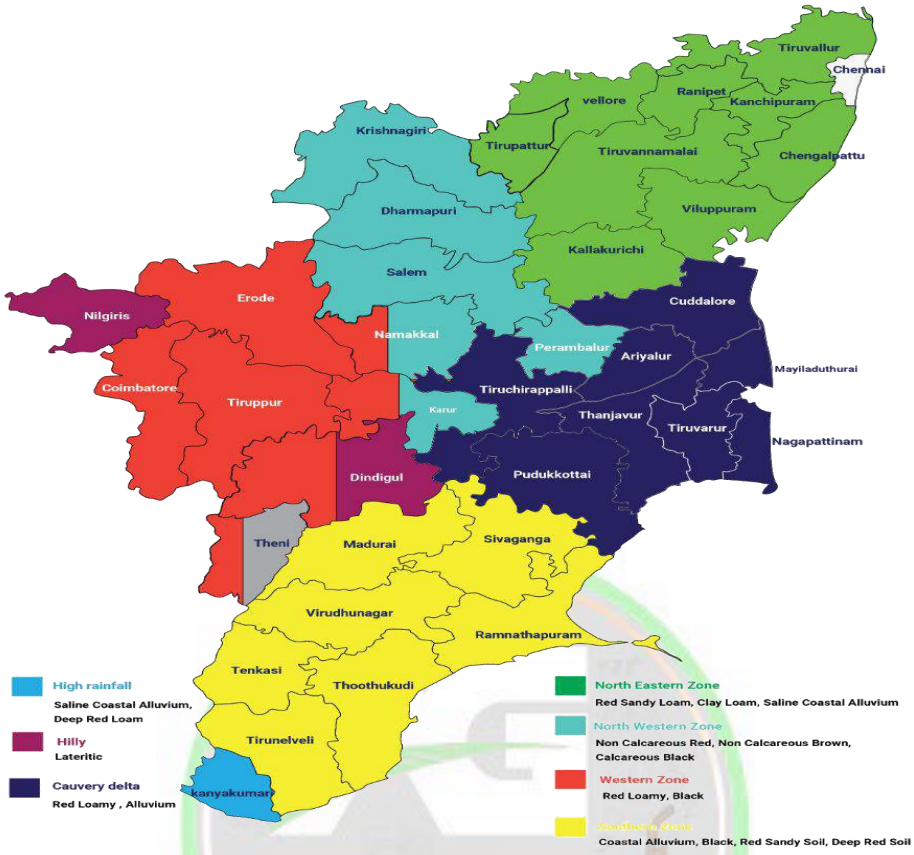


Figure 1. Location of the Cauvery Delta Zone within Tamil Nadu, India, showing the principal districts associated with the delta's rice-growing region.

2. Salinity Stress and Its Effects on Rice

2.1. Nature of salinity stress

Salinity results from the accumulation of soluble salts in the soil solution. Sodium chloride is commonly associated with coastal salinity, although other soluble salts can also contribute. Electrical conductivity (EC) is widely used to assess soil salinity, while pH, exchangeable sodium percentage, and ion composition help distinguish saline conditions from sodicity. Salinity affects plants through two principal processes: osmotic stress and ionic stress. Osmotic stress occurs when high concentrations of dissolved salts reduce the availability of water to roots. Ionic stress develops as excessive sodium (Na^+) and chloride (Cl^-) accumulate in plant tissues, interfering with cellular functions and nutrient balance.Initially, osmotic stress restricts water uptake and leaf expansion. Prolonged exposure may result in sodium accumulation, premature leaf senescence, membrane damage, and reduced photosynthetic

capacity. These responses are influenced by salinity intensity, exposure duration, developmental stage, and cultivar (Munns & Tester, 2008).

2.2. Effects on rice growth and yield

Salinity can reduce seed germination, root and shoot elongation, tillering, and biomass accumulation. Visible symptoms include leaf-tip burning, chlorosis, and necrosis. Sodium toxicity and potassium deficiency can further impair enzyme activity, photosynthesis, and cellular metabolism.Reproductive-stage stress is particularly important because salinity during panicle development, flowering, and grain filling can reduce spikelet fertility and grain yield. Therefore, tolerance during seedling establishment should not be assumed to guarantee tolerance during reproduction. For the Cauvery Delta, this distinction is important because exposure may vary across crop seasons. Screening programmes should assess both seedling survival and reproductive performance under salinity levels representative of affected agricultural locations.

3. Physiological Basis of Salt Tolerance in Rice

3.1. Ion exclusion and potassium homeostasis

Ion exclusion is a major mechanism of salt tolerance. Salt-tolerant plants restrict excessive sodium entry into roots, reduce its transport to the shoots, and maintain suitable concentrations of essential nutrients. Potassium (K^+) is essential for enzyme activation, protein synthesis, stomatal regulation, and osmotic balance. Excessive sodium competes with potassium uptake and disrupts the K^+/Na^+ balance required for normal cellular metabolism. Maintaining a favourable K^+/Na^+ ratio is therefore an important component of salt tolerance. The rice Saltol region contains genetic determinants associated with seedling-stage salinity tolerance. The gene *OsHKT1;5* encodes a sodium transporter that helps retrieve sodium from the xylem, thereby limiting its accumulation in shoots (Thomson *et al.*, 2010). However, sodium exclusion alone does not explain all differences in tolerance. Some genotypes can withstand relatively high tissue sodium concentrations by compartmentalising ions in vacuoles or restricting their accumulation in sensitive tissues. Both ion exclusion and tissue tolerance should therefore be considered during varietal selection.

3.2. Osmotic adjustment and water relations

Osmotic adjustment enables rice plants to maintain cellular water balance when soil water potential decreases under saline conditions. Plants accumulate compatible solutes, including proline and soluble sugars, which contribute to osmotic regulation and cellular

protection.Physiological measurements such as relative water content, leaf water potential, stomatal conductance, and leaf expansion help evaluate the ability of rice plants to maintain water relations under salinity.Aquaporins, which facilitate water movement across cellular membranes, may also contribute to water transport during stress. Their responses depend on the particular protein, tissue, developmental stage, and severity of exposure.In the Cauvery Delta, these mechanisms may be especially relevant where saline irrigation water and limited freshwater availability restrict crop water uptake.

3.3. Photosynthesis and chlorophyll stability

Salinity reduces photosynthetic performance through stomatal closure, ionic toxicity, oxidative damage, and changes in chloroplast function. Reduced carbon dioxide uptake limits carbon assimilation, while prolonged stress can accelerate chlorophyll degradation and leaf senescence. content, chlorophyll fluorescence, photosynthetic rate, and stomatal conductance are useful indicators for evaluating salt tolerance. However, chlorophyll retention alone is insufficient because plants may maintain pigment concentrations while experiencing substantial limitations in carbon assimilation or reproductive development. Salt-tolerant rice genotypes generally benefit from maintaining photosynthetic function, nutrient balance, and leaf integrity under comparable stress conditions (Negrao *et al.*, 2017).

3.4. Root development and nutrient acquisition

Root architecture influences water and nutrient uptake under saline conditions. Salinity may reduce root length, branching, and biomass, although the response varies with genotype and stress intensity. Excessive sodium can interfere with the uptake of potassium, calcium, and magnesium. Calcium contributes to membrane stability and cellular signalling, while potassium supports enzyme activity and osmotic regulation.Root length, root biomass, tissue ion concentrations, and nutrient status should be evaluated together. A longer root system does not necessarily indicate greater salt tolerance unless it is associated with improved plant water status, ionic balance, and growth.

4. Biochemical Basis of Salt Tolerance in Rice

4.1. Antioxidant defence

Salinity induces the production of reactive oxygen species (ROS), including superoxide radicals and hydrogen peroxide. Although ROS participate in signalling, excessive accumulation can damage membrane lipids, proteins, nucleic acids, and other cellular components.Rice plants

possess enzymatic and non-enzymatic antioxidant systems that regulate ROS concentrations. Important antioxidant enzymes include superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), and glutathione reductase (GR). SOD converts superoxide radicals into hydrogen peroxide, while CAT and APX contribute to hydrogen peroxide removal. Glutathione reductase helps maintain the reduced glutathione pool and cellular redox balance. Non-enzymatic antioxidants include ascorbate, glutathione, carotenoids, tocopherols, and phenolic compounds.

Effective antioxidant defence can reduce oxidative damage and support cellular function under salinity. However, greater enzyme activity does not automatically indicate greater tolerance because antioxidant responses may also increase in severely stressed plants. Enzyme activities should be interpreted alongside hydrogen peroxide, malondialdehyde (MDA), electrolyte leakage, growth, and ion concentrations (Gill & Tuteja, 2010).

4.2. Compatible solutes and osmoprotection

Compatible solutes are small organic compounds that accumulate in cells without substantially interfering with normal metabolic processes. They contribute to osmotic adjustment, protect proteins and membranes, and support stress recovery. Proline is widely investigated as a biochemical indicator of salinity responses. It may contribute to osmotic adjustment, protein stabilisation, and redox regulation. Soluble sugars provide energy and contribute to osmotic balance, while other compounds, including glycine betaine and trehalose, can have protective roles. The significance of these compounds varies among rice genotypes. High proline concentration may indicate an effective protective response, but it can also reflect severe stress. Biochemical measurements should therefore be combined with growth, water relations, and tissue ion analysis.

4.3. Membrane stability and oxidative injury

Excessive ROS production can damage cellular membranes through lipid peroxidation. Malondialdehyde is commonly used as an indicator of lipid peroxidation, while electrolyte leakage estimates membrane injury.Salt-tolerant plants may maintain lower MDA concentrations and reduced electrolyte leakage under equivalent stress conditions. These responses indicate better protection of cellular structures and more effective control of oxidative damage.Membrane stability is particularly important for rice leaves, where prolonged sodium accumulation can accelerate senescence and reduce photosynthetic activity.

4.4. Hormonal regulation

Plant hormones coordinate growth and stress responses. Abscisic acid (ABA) regulates stomatal closure, water conservation, and stress-responsive gene expression. However, prolonged stomatal closure may reduce photosynthesis. Ethylene influences root growth, senescence, and stress adaptation, while jasmonates and salicylic acid participate in stress signalling and defence responses. Their effects depend on concentration, timing, genotype, and interactions with other signalling pathways. Hormonal regulation should therefore be considered part of a coordinated response rather than the action of a single compound (Fujita *et al.*, 2011).

5. Molecular Basis of Salt Tolerance in Rice

5.1. Salt signalling pathways

Salinity triggers changes in osmotic conditions, cellular ion concentrations, calcium signalling, and ROS production. These changes activate signalling proteins and transcription factors that regulate stress-responsive gene expression. The salt overly sensitive (SOS) pathway is a well-established model for understanding sodium regulation in plants. It involves calcium sensing, protein kinase activity, and sodium/hydrogen exchange. In rice, ion transporters, calcium-dependent protein kinases, mitogen-activated protein kinase cascades, and hormone-associated signalling networks contribute to stress responses. These pathways regulate ion homeostasis, antioxidant defence, and osmotic adjustment. Their interactions help explain why salt tolerance is a complex trait involving multiple genes and physiological processes (Zhu, 2016).

5.2. Ion transporter genes

Ion transporters play an important role in regulating sodium uptake, distribution, sequestration, and potassium retention in rice plants under salinity stress. The *OsHKT1;5* transporter contributes to the retrieval of sodium from the xylem, thereby limiting excessive sodium accumulation in shoots. Its association with the Saltol quantitative trait locus makes it an important target for improving salinity tolerance in rice through molecular breeding (Thomson *et al.*, 2010). Similarly, members of the *OsNHX* gene family encode sodium/hydrogen exchangers involved in intracellular ion transport and homeostasis. Vacuolar NHX proteins may contribute to sodium sequestration within vacuoles, helping maintain cellular ion balance, although their functions vary among individual family members. The *OsSOS1* gene encodes a plasma-membrane sodium/hydrogen exchanger that contributes to sodium transport and cellular ion

regulation. In addition, potassium transporter families, including HAK and AKT, play important roles in potassium uptake and homeostasis, supporting essential metabolic activities under saline conditions. These ion transporter genes represent potential targets for molecular breeding to improve salinity tolerance in rice. However, their contributions should be evaluated in relation to tissue specificity, transporter activity, plant developmental stage, and overall plant performance under salt stress.

5.3. Transcription factors and stress-responsive genes

Transcription factors regulate groups of genes involved in salinity responses. Important families include NAC, WRKY, MYB, bZIP, and AP2/ERF. These transcription factors participate in the regulation of ion transport, antioxidant defence, osmotic adjustment, hormone signalling, and cellular protection. For example, bZIP proteins are involved in ABA-responsive gene regulation, while members of the NAC and WRKY families participate in stress-responsive transcriptional networks. The effectiveness of these regulatory mechanisms depends on genetic background and environmental conditions. Molecular studies increasingly emphasise the need to connect gene expression with physiological traits and field performance (Kumar *et al.*, 2021).

5.4. Molecular breeding and emerging technologies

Marker-assisted selection enables breeders to introduce validated salt-tolerance regions into locally adapted rice varieties. The Saltol region has been used to improve seedling-stage salinity tolerance, although its effects do not guarantee reproductive-stage tolerance. Genomic selection, transcriptomics, proteomics, metabolomics, and ionomics provide additional tools for understanding complex stress responses. Genome-editing technologies also offer opportunities to modify genes associated with ion transport and stress signalling. These approaches require careful evaluation because changes that improve stress tolerance may also affect plant growth, development, or yield under non-saline conditions. Multi-environment field testing is therefore essential before new cultivars are recommended for farmers.

6. Implications for the Cauvery Delta of Tamil Nadu

6.1. Regional salinity and environmental vulnerability

The Cauvery Delta is characterised by spatial variation in soil properties, irrigation sources, groundwater quality, and coastal influence. Coastal locations may be particularly vulnerable to seawater intrusion, while inland areas can have different soil and water constraints. Mohamed Tharik and Vijayaraghavalu (2024) investigated 177 groundwater samples from

coastal districts of Tamil Nadu, including Thanjavur, Tiruvarur, Nagapattinam, and Pudukkottai. Their hydrogeochemical assessment identified seawater mixing and irrigation-water quality concerns in parts of the study region. Pratheepa *et al.* (2023) also documented the relationship between coastal land degradation, seawater intrusion, and agricultural livelihoods in a village in the Cauvery Delta. These findings support the need for site-specific monitoring, but they should not be interpreted as evidence that all agricultural soils in the delta are saline. A regional assessment should therefore include soil EC, soil pH, exchangeable sodium percentage where appropriate, irrigation-water EC, groundwater depth, and seasonal variation. Such information can identify locations where salt-tolerant varieties or additional management interventions are justified.

6.2. Selection of suitable rice cultivars

Salt-tolerant varieties can reduce production risks in areas where salinity cannot be fully controlled. Selection should consider seedling survival, sodium exclusion, potassium retention, biomass maintenance, flowering performance, and grain yield. A 2026 study by Sakunthalai examined yield gaps among five salt-tolerant rice varieties in salt-affected areas of the Cauvery Delta. The study highlighted the importance of varietal choice, crop establishment, irrigation, and other farm-management factors. Its findings support an integrated approach in which improved varieties are combined with suitable agronomic practices. For the region, breeding programmes should evaluate varieties across seasons and representative saline environments. Seedling-stage screening should be complemented by reproductive-stage assessments because tolerance can differ substantially between developmental stages.

6.3. Integrated soil and water management

Genetic tolerance should be combined with appropriate soil and water management practices to reduce root-zone salinity and improve water availability. Freshwater should be prioritised during sensitive crop growth stages whenever adequate supplies are available and the water quality is suitable. Proper drainage facilities are essential for removing excess saline water from agricultural fields, provided that suitable drainage outlets are available and environmental impacts on neighbouring areas are minimised. Leaching with good-quality water can help remove soluble salts from the root zone when effective drainage is ensured; however, leaching without adequate drainage may not effectively reduce soil salinity. Groundwater quality should be regularly monitored, and excessive groundwater extraction should be avoided in coastal areas

vulnerable to seawater intrusion. Soil amendments such as gypsum may be applied to sodic soils based on soil-test results, but their use should not be considered a universal solution for all saline soils. Furthermore, sowing and transplanting schedules should be planned according to local water availability and seasonal salinity risks. The effectiveness of these management practices depends on soil characteristics, irrigation-water quality, groundwater depth, drainage infrastructure, and local hydrological conditions. Therefore, soil and water management recommendations should be developed according to the specific requirements of individual locations rather than applied uniformly throughout the Cauvery Delta region of Tamil Nadu.

6.4. Future research priorities

Future research should integrate physiological measurements, biochemical indicators, molecular analysis, and multi-environment field evaluation. Priority areas include identifying locally adapted rice genotypes, evaluating reproductive-stage tolerance, investigating interactions between salinity and drought or heat, and validating molecular markers under field conditions. High-throughput phenotyping and remote sensing may assist in identifying crop stress patterns across agricultural landscapes. Soil and groundwater monitoring can identify emerging salinity risks, while participatory breeding can help ensure that improved varieties meet farmers' requirements for yield, maturity, grain quality, and market acceptability.

Conclusion

Salt tolerance in rice is governed by interconnected physiological, biochemical, and molecular mechanisms. Sodium exclusion, potassium homeostasis, osmotic adjustment, antioxidant defence, membrane stability, hormonal regulation, and stress-responsive gene expression contribute to plant adaptation under saline conditions. Molecular discoveries involving the Saltol region and ion transporters provide opportunities for developing improved rice cultivars through marker-assisted selection and modern biotechnology.For the Cauvery Delta of Tamil Nadu, these advances must be applied within the context of local soil variability, groundwater quality, seasonal freshwater availability, and coastal vulnerability. Salinity should be assessed at the field level rather than assumed to occur uniformly throughout the delta. Combining appropriate cultivars with effective drainage, freshwater conservation, irrigation-water monitoring, and site-specific soil management offers a more reliable approach to sustaining rice productivity. Integrating molecular research with field-based evaluation and

farmer participation will be essential for developing resilient rice production systems in the Cauvery Delta.

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Volume: 06 Issue No: 10

FIGHTING SOIL SALINITY: THE POWER OF FOLIAR SPRAYS AND BENEFICIAL MICROBES

Article ID: AG-VO6-I10-81

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Abstract

Soil salinity quietly steals yield from farmers' fields across the world, and the usual remedies such as leaching and drainage are costly and not always possible. This article explains, in simple language, two low-cost and eco-friendly tools that help crops cope with salty soils: foliar sprays and beneficial microbes. Sprays of protective compounds, including proline, glycine betaine, salicylic acid and seaweed extracts, help leaves hold water, shield cells from damage and keep potassium levels balanced. Beneficial microbes, such as salt-tolerant root bacteria and mycorrhizal fungi, work below ground by improving nutrient uptake, reducing harmful stress induced ethylene and limiting sodium entry into plants. Used along with good water and soil management, these tools can help protect yield on salt-affected land.

Keywords: Soil salinity, Foliar spray, Biostimulants, PGPR, Mycorrhiza, Salt stress

Introduction

Walk through a salt-affected field and the signs are easy to read: a white crust on the surface, patchy germination, stunted plants and leaf tips that look scorched. FAO's 2024 assessment estimates that about 1,381 million hectares, or 10.7 per cent of the world's land, are salt-affected, and in the worst-hit countries yield losses in crops such as rice and beans can reach 70 percent.[1] Poor-quality irrigation water, inadequate drainage and the overuse of fertilisers add to the problem, and rising aridity is expected to make it worse.[1]

Salt harms plants in two ways. First, salt in the root zone makes it harder for roots to draw in water, which is called osmotic stress. Second, sodium and chloride enter the plant and build up to toxic levels, upsetting nutrient balance and creating damaging reactive oxygen molecules.[2] Fixing the soil itself through drainage, mulching and soil amendments remains essential, but it is slow and expensive.[1] Meanwhile, the crop standing in the field needs help now. Two farmer-friendly tools can provide it: foliar sprays that give leaves a protective boost, and beneficial microbes that act as the plant's partners in the root zone.

How Salt Hurts a Growing Crop

The damage begins before the seed has even sprouted. Salinity can slow or stop germination by upsetting the balance of the plant hormones that wake a seed up, and it weakens the seedlings that do emerge.[3] Later, the plant struggles on three fronts at once. It finds it harder to absorb water, it takes in too much sodium and chloride, and it produces harmful reactive oxygen molecules that injure leaves and membranes. Photosynthesis falls, growth slows and yield suffers.

This is why a single remedy rarely works. Good tools must reduce water stress, protect cells from damage and help roots take up the right nutrients. Foliar sprays and beneficial microbes each address a different part of this picture.

Foliar Sprays: A Quick Shield for Leaves

A foliar spray is a dilute solution applied directly on the leaves, which absorb it within hours. Under salt stress, plants try to protect themselves by making small protective molecules. Spraying these molecules, or natural materials that stimulate their production, gives the plant a head start.

Proline and glycine betaine

These two compounds are called compatible solutes. They help cells hold water, keep membranes and proteins stable and reduce oxidative damage.[3,4] In a study on maize grown in soils with salinity up to 10 dS/m, foliar proline or glycine betaine at 60 mM gave the best improvement in growth, chlorophyll content and potassium uptake.[5]

Salicylic acid

Salicylic acid is a natural signalling compound in plants. At low doses it strengthens the plant's own antioxidant defence and is widely tested as a salinity-protective spray, although the best dose differs from crop to crop.

Seaweed extracts

Seaweed extracts are natural biostimulants rich in minerals and growth-regulating compounds. A meta-analysis of cereal studies found that foliar seaweed extracts increased shoot and root biomass under both normal and salt-stress conditions, with dilute extracts (25 percent or less) working best.[6] Spraying works best in the cool early morning or evening, at the right dose and on a small test area first. Remember that sprays make the plant more tolerant; they do not remove salt from the soil.

Beneficial Microbes: Allies Below Ground

Salt-tolerant root bacteria (PGPR)

Plant growth promoting rhizobacteria live around roots, and salt-tolerant strains of genera such as *Bacillus, Pseudomonas* and *Enterobacter* have shown benefits under salinity.[2,8] They help in several ways. Some produce an enzyme, ACC deaminase, which lowers the stress ethylene that otherwise stunts roots. Others make auxin, a hormone that promotes root growth, or sticky exopolysaccharides that are thought to bind sodium and hold moisture near the roots.[2,8] These bacteria are usually applied as seed treatment, seedling root dip or soil drench.

Mycorrhizal fungi

Arbuscular mycorrhizal fungi form a partnership with the roots of more than 80 percent of land plants. Their fine threads reach water and nutrients that roots cannot, improving the uptake of phosphorus, nitrogen, calcium and magnesium, and helping the plant keep a healthy potassium to sodium ratio. Mycorrhizal plants also build up proline, soluble sugars and antioxidants that protect them from salt.[8,9] Very high salinity can itself reduce colonisation, so locally adapted, salt-tolerant strains and healthy soil life are important.[8]

Better Together: An Integrated Approach

Foliar sprays protect the plant from above while microbes support it from below, so the two tools complement each other. Studies that test them together in farmers' fields are still limited, so this combination should be treated as a promising practice rather than a guaranteed fix. A sensible plan for a salt-affected field is:

1. Manage the basics first: better irrigation water, drainage, mulching and suitable soil amendments.
2. Choose crop varieties known to tolerate salt.
3. Treat seed or seedlings with salt-tolerant bacteria or mycorrhizal inoculants.

4. Add organic matter to feed soil life.
5. Apply foliar sprays at critical stages such as seedling establishment and flowering.

Most results quoted here come from pot or controlled trials. Farmers should check dose, crop and product recommendations with the local agricultural university or Krishi Vigyan Kendra, and prefer quality-tested products.

Practical Tips for Farmers

- Test first: check soil or irrigation water salinity (EC) so that you know how serious the problem is.
- Start small: try any spray or inoculant on a small plot before treating the whole field.
- Spray in the cool early morning or late evening so that leaves absorb the solution without scorching.
- Repeat at intervals: most trials use more than one spray, usually timed to sensitive growth stages.
- Protect the microbes: heavy doses of fungicide or phosphate fertiliser can reduce the benefit of inoculants.
- Keep records of dose, date and crop response, so that the next season's decisions are based on your own field evidence.

Conclusion

Soil salinity is a growing challenge, but crops need not be left defenceless. Foliar sprays of protective compounds and seaweed extracts, together with salt-tolerant bacteria and mycorrhizal fungi, offer low-cost and eco-friendly support that works alongside proper water and soil management. With careful dosing and local testing, these tools can help farmers protect yield and keep salt-affected land productive.

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Volume: 06 Issue No: 10

DEATH HAS MANY FACES: EXPLORING PANOPTOSIS IN FISH PATHOLOGY

Article ID: AG-VO6-I10-82

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Abstract

Cell death is an essential biological process that contributes to the development, maintenance and defence of tissues and organs in fish. Traditionally, pyroptosis, apoptosis and necroptosis have been studied as distinct forms of regulated cell death. However, growing evidence has revealed interactions among these pathways, leading to the emergence of a concept known as PANoptosis. PANoptosis is an inflammatory form of regulated cell death involving interconnected molecular mechanisms associated with pyroptosis, apoptosis and necroptosis. A multiprotein signalling complex known as the PANoptosome plays a central role in coordinating these mechanisms. In mammals, PANoptosis has been associated with immune responses, inflammation and infectious diseases. However, its molecular mechanisms and biological significance in fish remain incompletely understood. This article explores the three major cell-death pathways, their interactions in PANoptosis and emerging evidence from fish research. It also highlights the importance of understanding PANoptosis in host–pathogen interactions, inflammation and disease progression, while identifying key areas for future research in fish pathology and aquatic animal health management.

Keywords: PANoptosis; Pyroptosis; Apoptosis; Necroptosis; Fish pathology; Regulated cell death.

1. Introduction

Cell death is not always the end - it can also be a defence strategy. In healthy organisms, removing damaged, infected or harmful cells is essential for maintaining normal tissue structure and physiological functions. When cells are exposed to pathogens, environmental stress or other harmful substances, they may undergo regulated cell death. Traditionally, apoptosis, pyroptosis and necroptosis have been studied as distinct forms of regulated cell death, each with characteristic molecular mechanisms and biological consequences. However, research has revealed that these pathways do not always act independently. They can interact and share molecular components, particularly during infection and inflammation. This interconnected nature of regulated cell death has led to the emergence of a new concept known as PANoptosis. PANoptosis provides a new perspective on how different cell death pathways interact during infection and inflammation. Although this process has been studied extensively in mammals, research on its molecular mechanisms and biological significance in fish is still developing. Exploring PANoptosis in fish may help researchers better understand host-pathogen interactions, inflammatory responses and tissue damage during infectious diseases, opening new avenues for research in aquatic animal health.

2. WHAT IS PANOPTOSIS

PANoptosis is an inflammatory form of regulated cell death involving interconnected molecular mechanisms associated with three major cell-death pathways: pyroptosis, apoptosis and necroptosis. A multiprotein signalling complex known as the PANoptosome plays a central role in coordinating PANoptosis.

The term PANoptosis combines:

- ✓ P → Pyroptosis
- ✓ A → Apoptosis
- ✓ N → Necroptosis

3. THE THREE FACES OF PANOPTOSIS

To understand PANoptosis, it is first necessary to understand the three cell death pathways associated with it.

3.1 Pyroptosis – The Inflammatory Face

Pyroptosis is an inflammatory form of regulated cell death that contributes to the host's defence against infection. The process begins when the host recognises pathogens or danger

signals through pattern-recognition receptors (PRRs), including Toll-like receptors (TLRs), NOD-like receptors (NLRs) and RIG-I-like receptors (RLRs). These receptors participate in pathogen recognition and innate immune signalling. Certain intracellular sensors can activate inflammasomes, which are multiprotein complexes involved in the activation of inflammatory caspases. These caspases activate gasdermin proteins, which form pores in the cell membrane. Consequently, the cell may swell and rupture, releasing cellular contents that promote inflammation. Although pyroptosis can contribute to host defence, excessive activation may also cause inflammation and tissue injury.

Mechanism of pyroptosis :

Pathogen or danger signals

↓

Pathogen recognition by PRRs and intracellular sensors

↓

Inflammasome activation

↓

Inflammatory caspase activation

↓

Gasdermin activation

↓

Pore formation in the cell membrane

↓

Cell swelling and membrane rupture

↓

Release of cellular contents and inflammatory responses

Evidence in fish :

Evidence of pyroptosis - associated mechanisms has been reported in fish. In zebrafish, the intracellular sensor Caspy2 recognises bacterial lipopolysaccharide (LPS) and mediates pyroptosis during Gram-negative bacterial infection, contributing to innate immune responses. In Japanese flounder, infection with *Edwardsiella piscicida* activates the NLRP3 inflammasome, resulting in caspase-1 activation and IL-1β maturation. This inflammasome contributes to antibacterial defence by helping restrict bacterial colonisation. Together, these studies highlight

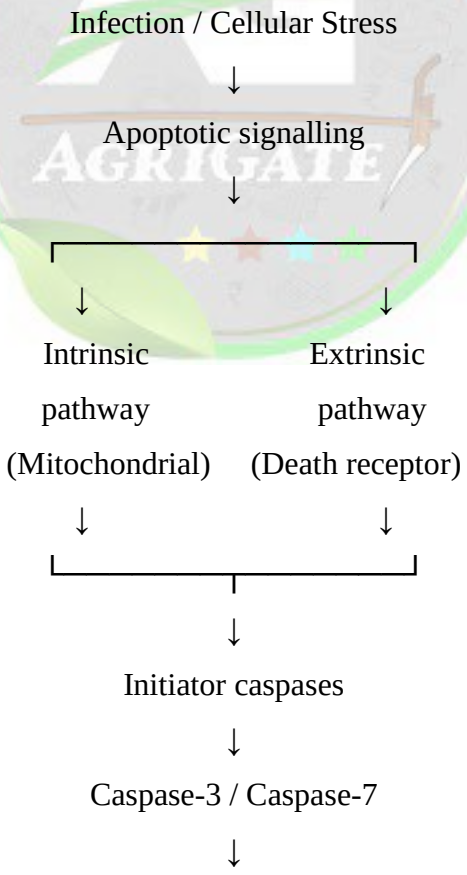
the importance of inflammasome-associated mechanisms in fish innate immunity, although activation of an inflammasome does not, by itself, establish that pyroptotic cell death has occurred.

3.2 Apoptosis – The Silent Face

Apoptosis is a regulated form of cell death that removes damaged, infected or unwanted cells in a controlled manner. Unlike pyroptosis, which is associated with inflammation, apoptosis generally occurs without triggering a strong inflammatory response. It is essential for normal development, tissue maintenance and immune regulation. It is regulated by a cascade of caspase enzymes, particularly executioner caspases such as caspase-3 and caspase-7, which ultimately lead to controlled cellular breakdown.

During infection, apoptosis can contribute to host defence by eliminating infected cells and limiting the spread of pathogens. However, pathogens can also manipulate apoptotic pathways to promote their survival.

Mechanism of apoptosis :



Controlled cell dismantling

↓

Removal of damaged/infected cell

Evidence in fish:

In crucian carp (*Carassius auratus*) infected with *Rahnella aquatilis*, researchers used TUNEL staining to identify cells showing DNA fragmentation and investigated changes in immune and inflammatory gene expression associated with the apoptosis pathway. These findings provide evidence of apoptosis-associated responses during bacterial infection in fish. However, apoptosis-associated responses alone do not establish the occurrence of PANoptosis.

3.3 Necroptosis – The Lytic Face

Necroptosis is a regulated form of cell death that exhibits morphological features similar to necrosis. Unlike traditional necrosis, which was considered passive and uncontrolled, necroptosis is an actively regulated process. It is generally caspase-independent and can result in membrane disruption and cell lysis, leading to the release of cellular contents and inflammation.

The classical necroptosis pathway involves receptor-interacting protein kinase 1 (RIPK1), receptor-interacting protein kinase 3 (RIPK3) and mixed lineage kinase domain-like protein (MLKL). In the commonly described TNF-induced pathway, signalling through tumour necrosis factor receptor 1 (TNFR1) can activate RIPK1 and promote RIPK3 activation. RIPK3 then phosphorylates MLKL, which contributes to plasma membrane disruption and cell rupture.

Mechanism of necroptosis:

Cellular stress or death-receptor signalling

↓

RIPK1 - associated signalling

↓

RIPK3 activation

↓

MLKL phosphorylation

↓

MLKL mediated membrane disruption

↓

Membrane permeabilisation

↓

Cell lysis and inflammation

Evidence in fish

Necroptosis-associated responses have been investigated in fish during infectious diseases. In crucian carp (*Carassius auratus gibelio*) infected with cyprinid herpesvirus 2 (CyHV-2), transcriptomic and proteomic analyses revealed changes associated with the necroptosis pathway, suggesting its possible involvement in the host response to viral infection. These findings highlight the need for further research into the role of necroptosis in fish diseases. However, functional studies are required to confirm necroptosis and determine its influence on disease progression.

4. PANOPTOSIS: WHERE THE THREE FACES MEET

During infection, the signalling pathways involved in pyroptosis, apoptosis and necroptosis may interact rather than function entirely independently. They can share molecular components and influence one another, allowing different cell-death mechanisms to participate in a coordinated response. Such interactions are particularly relevant during infection and inflammation, when the host must respond to pathogens while maintaining tissue integrity.

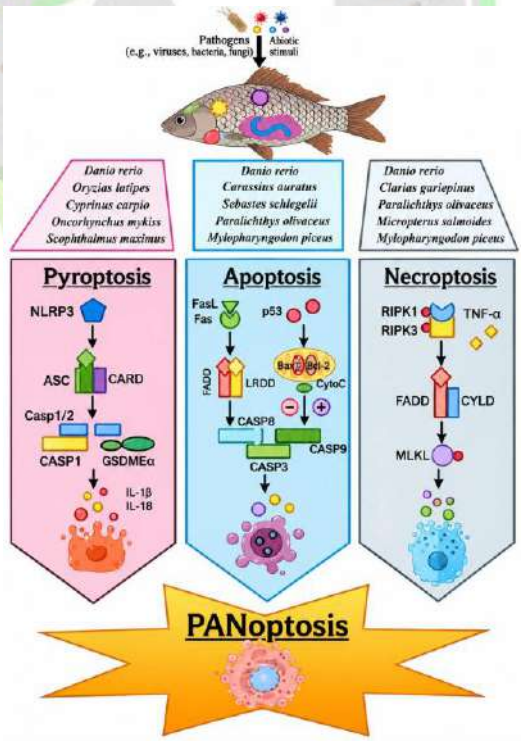


Figure 1. Conceptual model illustrating the potential interactions among pyroptosis, apoptosis and necroptosis during PANoptosis in fish. *Based on Jin et al. (2025).*

The PANoptosome is a multiprotein signalling complex that coordinates molecular components associated with these cell-death pathways. However, detecting markers associated with pyroptosis, apoptosis and necroptosis does not, by itself, confirm PANoptosis. Molecular and functional evidence is needed to establish whether these pathways are coordinated within a PANoptotic response.

Research on PANoptosis in fish is still emerging. In a 2025 study, Liu and colleagues investigated VgrG-associated PANoptosis-related responses in macrophages of crucian carp (*Carassius auratus*) following infection with *Rahnella aquatilis*. Their dual RNA-sequencing analysis provided insights into changes in host and pathogen gene expression associated with PANoptosis-related mechanisms. This study offers a fish-specific example of research into the interactions between bacterial infection and regulated cell-death pathways. Nevertheless, the molecular organisation of fish PANoptosomes and their roles in different fish species and infectious diseases require further investigation

5. WHY DOES PANOPTOSIS MATTER IN FISH PATHOLOGY?

PANoptosis provides a broader perspective on how regulated cell death influences the outcome of infections in fish. Understanding the interactions between pyroptosis, apoptosis and necroptosis may help explain the complex relationship between cell death, inflammation, pathogen clearance and disease progression.

In fish pathology, this perspective may improve our understanding of host–pathogen interactions and the cellular mechanisms involved in disease development. Further research into PANoptosis could also help identify molecular targets for investigating disease processes and developing future research into fish health management in aquaculture.

6. FROM DEFENCE TO DAMAGE: THE DOUBLE-EDGED SWORD

Although regulated cell death contributes to host defence, its effects may depend on the intensity and coordination of the response. Appropriate activation of cell-death pathways may help control infections, whereas excessive or dysregulated activation can intensify inflammation and damage surrounding tissues.

Thus, PANoptosis may represent a double-edged sword during infection: it may contribute to pathogen control, but it may also be associated with inflammatory injury. Understanding this balance is important for investigating how cellular defence mechanisms influence disease severity and tissue damage in fish.

7. FUTURE PERSPECTIVES

Research on PANoptosis in fish is still at an early stage, and several important questions remain unanswered. Future studies should investigate the molecular components of fish PANoptosomes and clarify how pyroptosis, apoptosis and necroptosis interact during infection. Experimental approaches combining gene-expression analysis, protein characterisation and functional validation are needed to distinguish coordinated PANoptosis from the activation of individual cell-death pathways. Further research across different fish species and infectious diseases could also reveal how these mechanisms influence host defence, inflammation and tissue damage. Such investigations will be important for establishing the biological significance of PANoptosis in fish and assessing its potential relevance to aquatic animal health management.

Conclusion

PANoptosis is an emerging concept that highlights the interconnected nature of pyroptosis, apoptosis and necroptosis during infection and inflammation. In fish, these interactions may influence host–pathogen relationships, pathogen clearance and tissue damage. Although regulated cell death can contribute to host defence, dysregulated responses may intensify inflammation and tissue injury. A clearer understanding of PANoptosis in fish could therefore provide valuable insights into disease mechanisms and support future research into disease prevention and management in aquaculture.

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Volume: 06 Issue No: 10

APPLICATION OF MOLECULAR MARKERS IN MODERN PLANT BREEDING FOR CROP IMPROVEMENT: A REVIEW

Article ID: AG-VO6-I10-83

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Abstract

Plant breeding is an essential component of agricultural development because it contributes to the production of crop varieties with improved yield, quality, and resistance to environmental stresses. Traditional breeding methods have made substantial contributions to crop improvement, but their effectiveness can be limited by the time required for plant evaluation and the influence of environmental conditions on observable traits. Molecular marker technology provides an additional approach by enabling the identification of genetic differences associated with desirable plant characteristics. This review examines the principles, major types, applications, advantages, and limitations of molecular markers in modern plant breeding. It discusses the use of restriction fragment length polymorphism (RFLP), simple sequence repeats (SSR), amplified fragment length polymorphism (AFLP), and single nucleotide polymorphism (SNP) markers in genetic diversity assessment, gene mapping, marker-assisted selection, and the development of improved crop varieties. The review also considers the integration of molecular markers with genomic selection, genome-wide association studies, and genome-editing technologies. The literature indicates that molecular approaches can improve selection efficiency, support the transfer of useful genes, and contribute to the development of crops with improved disease resistance and tolerance to abiotic stresses. However, their successful application depends on marker reliability, genetic background, available resources, and accurate field evaluation. Integrating molecular information with conventional breeding and appropriate agronomic assessment offers a promising strategy for sustainable crop improvement.

Keywords: Genetics, Plant Breeding, molecular markers, MAS, SNP, SSR, Crop improvement

Introduction

Agriculture is increasingly required to provide adequate food, feed, and industrial raw materials while responding to climate variability, changing pest and disease pressures, and limitations in natural resources. Plant breeding contributes to these objectives by developing crop varieties with desirable characteristics, including higher productivity, improved nutritional quality, uniform maturity, and greater tolerance to environmental stress.

Conventional plant breeding relies on the selection and crossing of plants with favourable characteristics. Although these methods remain important, the selection process can become difficult when a trait is controlled by several genes, expressed only at a particular developmental stage, or strongly influenced by environmental conditions. For example, selecting plants for drought tolerance based only on their appearance in the field may not always distinguish genetic tolerance from differences in soil moisture or other environmental factors.

Molecular genetics has introduced methods for examining plant DNA directly. Molecular markers are identifiable DNA variations that can be used to distinguish genotypes and investigate associations between genetic regions and particular traits. These markers allow breeders to obtain genetic information even when a characteristic cannot be assessed reliably through visual observation alone.

Marker-assisted selection (MAS) uses DNA markers associated with desirable genes or genomic regions to support the selection of plants during a breeding programme. It can be particularly useful for traits such as disease resistance, grain quality, and the transfer of specific genes between breeding lines. Modern marker systems also support genetic diversity studies, linkage mapping, and the identification of genomic regions involved in complex traits.

Recent developments in sequencing technologies, bioinformatics, and genome analysis have expanded the role of molecular information in crop improvement. Molecular markers can now be integrated with genomic selection and other advanced breeding approaches to improve the understanding and management of genetic variation (Kumar et al., 2024).

The present review examines how molecular marker technologies contribute to modern plant breeding, identifies their major applications, and discusses the practical considerations involved in their use for sustainable crop improvement.

Objectives of the Review

1. To describe the major types of molecular markers used in plant breeding.

2. To examine the role of molecular markers in genetic diversity assessment and gene mapping.

3. To explain the applications of marker-assisted selection in crop improvement.

4. To evaluate the advantages and limitations of molecular breeding approaches.

5. To identify future opportunities for integrating molecular genetics with conventional plant breeding.

Review of Literature

Development of molecular marker technology

The development of DNA-based marker systems has strengthened the relationship between molecular genetics and practical crop improvement. Earlier breeding programmes primarily relied on observable characteristics, whereas molecular marker techniques made it possible to identify genetic differences directly. This development provided new opportunities for studying inheritance, identifying linked genes, and characterising plant populations.

Collard and Mackill (2008) discussed the importance of marker-assisted selection in practical plant breeding, particularly for improving the efficiency of selecting useful traits. Their work emphasised the need to combine molecular information with conventional breeding knowledge rather than treating marker technology as a replacement for field evaluation.

Major types of molecular markers

Molecular markers differ in their detection methods, reproducibility, cost, and ability to distinguish genetic variants.

Restriction fragment length polymorphism (RFLP): This method identifies differences in DNA fragment lengths following restriction enzyme digestion. It contributed significantly to early genetic mapping studies but generally requires more laboratory effort than many modern marker systems.

Random amplified polymorphic DNA (RAPD): RAPD uses short primers to amplify different regions of genomic DNA. It can be relatively simple to perform, although reproducibility may be affected by laboratory conditions.

Amplified fragment length polymorphism (AFLP): AFLP combines restriction digestion and selective amplification to detect variation across multiple DNA regions. It has been used in genetic diversity studies and population analysis.

Simple sequence repeats (SSR): SSR markers examine differences in the number of repeated DNA sequence units at particular genomic locations.

They are useful for genetic diversity analysis, cultivar identification, and linkage mapping. Single nucleotide polymorphism (SNP): SNP markers identify variations at individual nucleotide positions. Their abundance across plant genomes makes them particularly valuable for high-throughput genotyping, genome-wide association studies, and genomic selection.

Collard and Mackill (2008) and the review by Nair and Pandey (2024) provide useful discussions of molecular marker systems and their applications in crop breeding.

Marker-assisted selection in crop improvement

Marker-assisted selection uses genetic markers linked to desirable traits to identify promising plants. Unlike selection based entirely on observable characteristics, MAS provides information about the presence of particular genetic regions.

MAS is especially useful when a target trait is controlled by one or a few major genes, when phenotyping is costly or difficult, or when breeders need to transfer a gene into an established variety. It can also assist in gene pyramiding, in which several resistance genes are combined in the same genetic background.

Collard and Mackill (2008) highlighted the practical value of MAS in breeding programmes, while Nair and Pandey (2024) reviewed its relationship with different molecular marker systems and crop improvement objectives.

Molecular markers and genetic diversity

Genetic diversity is the variation present within and between plant populations. It provides the raw material needed for crop improvement and helps breeders identify genetically distinct parents for crossing programmes.

SSR and SNP markers can be used to estimate genetic relationships, distinguish accessions, identify duplicates in germplasm collections, and examine population structure. Such information can assist in choosing parents with complementary characteristics and in conserving valuable genetic resources.

However, genetic distance alone does not guarantee superior hybrid performance. Molecular diversity information should therefore be considered alongside agronomic performance, combining ability, and the objectives of the breeding programme.

Integration with genomic technologies

Modern plant breeding increasingly combines molecular markers with genome-wide association studies (GWAS), genomic selection, high-throughput sequencing, genome editing.

GWAS examines statistical associations between genetic variants and traits across diverse populations. Genomic selection uses information from many markers across the genome to predict the breeding value of individuals. Genome editing, including CRISPR-based methods, directly modifies targeted DNA sequences and is distinct from conventional marker-assisted selection.

Kumar et al. (2024) reviewed the contribution of molecular markers, genomic selection, and genome editing to modern plant breeding. Sun et al. (2024) also examined the integration of molecular approaches, genetic diversity analysis, and emerging technologies in crop improvement.

These developments suggest that future breeding programmes will increasingly combine genetic information, reliable phenotyping, and field-based evaluation to select plants suited to specific agricultural environments.

Research Methodology

Research design

The present article adopts a narrative review methodology. It synthesises published scientific literature concerning molecular markers, genetic diversity, marker-assisted selection, and modern plant breeding. It does not report a new laboratory experiment or original field trial.

Sources of information

Relevant literature may be identified through scientific databases and scholarly platforms, including PubMed, PubMed Central, ScienceDirect, SpringerLink, and Google Scholar. Priority should be given to peer-reviewed research articles, review papers, and publications directly related to molecular genetics and crop improvement.

Literature selection criteria

The review focuses on publications addressing one or more of the following areas:

- Principles and classification of molecular markers.
- Applications of SSR, SNP, AFLP, and related marker systems.
- Marker-assisted selection and gene mapping.
- Genetic diversity and germplasm characterisation.
- Genomic selection and emerging molecular breeding technologies.
- Advantages, technical limitations, and future prospects of molecular breeding.

Publications that do not directly contribute to the review objectives should be excluded. For a formal journal submission, the author should document the actual search dates, search terms, inclusion criteria, and number of articles screened and included.

Method of analysis

The selected literature is organised thematically into five areas: molecular marker systems, genetic diversity, marker-assisted selection, integration with modern breeding technologies, and implementation challenges. Findings are compared qualitatively to identify common applications, practical benefits, and limitations.

Ethical and scientific considerations

As this is a literature-based review, no new experiments involving plants, animals, or human participants are reported. All sources used in the final manuscript should be cited accurately, and the author should verify the original publications before submission.

Results

Major findings from the literature

The literature reviewed indicates that molecular markers have several important roles in plant breeding. The following findings represent a qualitative synthesis of published work, not measurements obtained from a new experiment.

1. Improved identification of genetic variation

Molecular markers provide information about genetic differences that may not be visible through conventional observation. SSR and SNP markers are particularly useful for characterising germplasm, identifying genetic relationships, and distinguishing plant genotypes.

2. More targeted selection of desirable traits

Marker-assisted selection can help identify plants carrying target genes or genomic regions. This is useful for traits such as disease resistance and particular quality characteristics, provided the marker has been validated in the relevant genetic background.

3. Support for combining useful genes

Molecular markers can help breeders select individuals carrying multiple target genes. Gene pyramiding is especially relevant when a crop needs resistance to more than one pathogen or pathogen strain.

4. Better understanding of complex traits

Genome-wide marker data can support the investigation of quantitative traits, including

yield, maturity, and stress tolerance. However, these traits are generally influenced by multiple genes and environmental conditions, so their improvement requires reliable phenotyping and appropriate statistical analysis.

5. Integration with advanced breeding systems

Sequencing, GWAS, genomic selection, and bioinformatics have expanded the possibilities for using molecular data. These methods can help breeders study complex genetic relationships and prioritise promising breeding material.

Constraints identified in the literature

Despite their potential, molecular marker technologies have limitations. Developing and validating markers may require specialised equipment, technical expertise, and financial resources. A marker associated with a trait in one population may not predict that trait equally well in another population because of differences in genetic background and linkage relationships.

Furthermore, a genetic association does not always demonstrate a direct causal relationship. Traits such as yield and drought tolerance may depend on multiple genes, environmental conditions, and interactions between genotype and environment. Therefore, marker results should be verified using appropriate field trials and phenotypic measurements.

Overall, the literature supports using molecular markers as part of an integrated breeding strategy rather than as a substitute for conventional selection and agronomic evaluation.

Conclusion

Molecular markers have become valuable tools in modern plant breeding because they provide information about genetic variation and the inheritance of desirable characteristics. Their applications include genetic diversity assessment, gene mapping, cultivar identification, marker-assisted selection, and the transfer or combination of useful genes. SSR and SNP markers have particular value in genetic characterisation and high-throughput analysis, while different marker systems remain useful depending on the research objective. Integration with genomic selection, GWAS, and other molecular technologies has expanded the opportunities for improving crop productivity, quality, and resilience. Nevertheless, successful molecular breeding requires reliable marker–trait associations, suitable laboratory facilities, skilled personnel, and accurate field evaluation. Molecular data should be interpreted alongside conventional breeding information and environmental performance.

Future crop improvement programmes should focus on affordable genotyping, validation across diverse genetic backgrounds, better phenotyping, and the responsible integration of molecular and conventional breeding techniques. Such an approach can strengthen the development of productive, resilient, and agriculturally suitable crop varieties.

Summery

This review examined the role of molecular markers in genetics and plant breeding. It discussed major marker systems, including RFLP, RAPD, AFLP, SSR, and SNP, and described their applications in genetic diversity analysis, gene mapping, and marker-assisted selection. The review indicates that molecular markers can improve the identification of desirable genetic characteristics and support the development of crop varieties with useful agronomic traits. Their integration with genomic selection, genome-wide association studies, and genome-editing technologies offers further opportunities for crop improvement.However, molecular breeding is most effective when genetic information is combined with reliable phenotyping, field evaluation, and appropriate statistical analysis. Wider access to affordable technologies and validation of marker–trait relationships will be important for expanding the practical benefits of molecular genetics in agriculture.

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Volume: 06 Issue No: 10

NANOTECHNOLOGY FOR SUSTAINABLE SOIL FERTILITY: OPPORTUNITIES AND LIMITATIONS

Article ID: AG-VO6-I10-84

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1. Introduction: A Fertility Problem Hiding in Plain Sight

Most of the fertiliser we put on fields never reaches the crop. Widely cited estimates put nitrogen use efficiency in cereals at roughly 40–50%, and the first-year recovery of applied phosphorus is far lower. The rest is lost to leaching, runoff, ammonia volatilisation and nitrous oxide emissions, or locked into forms plants cannot use. That waste is costly in three ways. Farmers pay for nutrients that never feed a crop. Governments, especially in import-dependent countries such as India, carry heavy fertiliser subsidy bills. And ecosystems absorb the damage: polluted groundwater, algal blooms in lakes and rivers, and greenhouse gases.

Over-use also erodes the soil itself. Heavy, unbalanced fertiliser application can acidify soil, upset nutrient ratios and disturb the microbial communities that cycle nutrients. A 2026 review of nano-biofertilisers, still awaiting peer review, opens by framing declining soil health as the central challenge for sustaining crop productivity. Nanotechnology has been offered as a way out. The pitch is simple: if nutrients are packaged at the nanoscale, plants can take up more of them, less is wasted, and farmers can apply less. Since 2021 this idea has moved from laboratory papers to commercial products, most visibly India's liquid nano urea.

The reality is more mixed than the pitch. Laboratory and pot studies are often encouraging, a large 2024 meta-analysis found real average gains, yet independent field trials of some commercial products have disappointed. This article sets out what nanotechnology can and

cannot do for soil fertility, as of October 2026, in plain language.

2. Nanotechnology 101: Why Size Changes Everything

A nanometre is one-billionth of a metre. Materials are called nanomaterials when they have at least one dimension between about 1 and 100 nm. For scale, a human hair is roughly 80,000 nm wide, and a typical soil clay particle is hundreds to thousands of nanometres across.

Shrinking a material does not just make it smaller. It changes how it behaves, mainly for two reasons.

- **More surface per gram.** Smaller particles expose far more surface area relative to their volume, so they dissolve faster, react more readily and can carry more of a nutrient on their surface.
- **New physical and chemical behaviour.** At this scale, charge, solubility and reactivity can differ from the same substance in bulk form. Reviews of inorganic nano-fertilisers link particle size, shape, crystal structure and clumping (agglomeration) directly to how well plants use the nutrient (Madlala et al., 2024).

How nano-materials meet the soil

Soil is not a clean test tube. It is a crowded mix of mineral particles, organic matter, water, roots, fungi and bacteria. A nanoparticle added to soil can:

1. stick to clay and organic matter, which may hold it in place;
2. dissolve and release nutrient ions;
3. clump together and lose its nanoscale properties, becoming unavailable to plants;
4. move into roots or leaves, or be taken up by microbes.

Which of these happens depends on soil pH, texture, organic matter, moisture and the particle's coating. This is why the same product can behave differently from one field to the next, a point the 2025 review "Beyond the hype" stresses (Buthelezi et al., 2025).

Two routes to the plant

Nano-fertilisers reach crops in two main ways: applied to soil, or sprayed on leaves (foliar). Foliar sprays are attractive because they bypass the soil's many loss pathways. But leaves can absorb only so much, which matters for nutrients needed in large amounts such as nitrogen. We return to this limit in Section 6.

3. The Nano Toolbox: What Is Actually on Offer

"Nano-fertiliser" is an umbrella term. A 2026 review in *Plants* sorts the field into six groups: macronutrient, micronutrient, organic, slow/controlled-release, composite and nano-enhanced formulations (Zhang et al., 2026). The table below simplifies this into the forms a farmer or student is most likely to meet.

Type	What it is	Main idea	Maturity
Nano-macronutrient fertilisers	Nitrogen, phosphorus or potassium in nanoscale form, e.g. nano urea, nano DAP, nano-hydroxyapatite	Higher uptake from small doses, mostly by foliar spray	Commercial in India; research elsewhere
Nano-micronutrient fertilisers	Zinc, iron, copper, manganese or silicon as nano-oxides or chelates	Correct deficiencies with tiny amounts	Mostly research and pilot scale
Slow/controlled-release carriers	Nutrients held in nanoclays, zeolites, polymers or chitosan that release gradually	Match nutrient supply to crop demand; cut leaching	Research, some coated products
Nano-biofertilisers	Beneficial microbes combined with nanocarriers	Better microbe survival and root colonisation	Early research
Nano-sensors	Nanoscale probes that detect moisture, nutrients or pH	Feed precision fertilisation	Research and early pilots
Nano-remediators	Nanomaterials that bind or immobilise soil contaminants such as heavy metals	Restore polluted soil	Research, limited field use

Products that exist today

The best-known commercial product is IFFCO's liquid nano urea, launched in India in June 2021. The company marketed a 500 ml bottle as a replacement for a 45 kg bag of conventional urea (Down To Earth). A nano DAP followed, and in March 2026 India formally notified 14 nano-fertiliser products under its Fertiliser Control Order, including nano urea and nano DAP from several manufacturers (Global Agriculture).

A note on "nano"

Whether a product truly contains nanoscale particles is a fair question, and it is one reason India's new rules require nano-scale validation of notified products. For readers, the practical lesson is to ask what was measured: particle size, how it was measured, and whether the claim comes from independent trials.

4. Opportunities: Where Nanotechnology Can Genuinely Help

The case for nano-inputs rests on five ideas. Each has some supporting evidence, though the strength varies.

4.1 Using nutrients more efficiently

Reviews of the literature report nutrient-use-efficiency gains of up to about 30% and yield gains of up to about 20%, with the potential to replace up to half of conventional fertiliser in some systems (Discover Applied Sciences, 2024). These are best-case figures from published studies, often under controlled conditions, so they should be read as potential rather than a promise.

A field study in Bangladeshi rice, run across six agro-ecological zones over the 2022–23 and 2023–24 Boro seasons, found that nano urea maintained yield with up to one-third less conventional urea (Bangladesh Rice Journal). The pattern matters: nano products worked as a partial substitute, not a full replacement.

4.2 Fewer losses to air and water

Slow-release carriers such as nanoclays, zeolites and polymer-coated particles hold nutrients and release them gradually. In principle this reduces nitrate leaching and ammonia loss, which protects water quality and lowers emissions (Channab et al., 2024). This is among the most plausible benefits for soil fertility, because it keeps nutrients in the root zone longer.

4.3 Fixing micronutrient gaps

Zinc, iron and silicon deficiencies are widespread and hard to fix with bulk fertilisers, which often become insoluble in soil. Nano forms can deliver very small doses precisely, and some studies report better crop quality and nutrient content as a bonus.

4.4 Cleaning and protecting contaminated soil

The strongest recent evidence comes from a large meta-analysis led by Baoshan Xing's group, published in *Nature Food* in 2024. It pooled 8,585 paired observations from 14 countries. Nano-materials outperformed conventional fertilisers at easing the harm of polluted soil by

38.3%, raised crop yield by 22.8% and improved crop nutritional value by 30%, on average (UMass Amherst). The authors were careful to add that nano-materials are not a silver bullet and must be matched to the crop and soil.

4.5 Smarter, precision fertilisation

Nano-sensors that read soil moisture, nutrient levels or pH could be paired with targeted fertiliser applications, so that nutrients are supplied where and when needed (Gupta et al., 2025). This is promising but mostly at the research stage; affordable field-ready sensors for smallholders remain scarce.

The honest summary

The opportunity is real but narrow: better efficiency, lower losses and targeted fixes. It is not a replacement for building soil organic matter, rotating crops and balancing nutrients.

5. The Evidence Test: India's Nano Urea Experience

No country has run a bigger real-world experiment than India. Nano urea was launched in 2021 with strong claims, promoted by the government and cooperatives, and then examined by independent scientists. The results are a useful lesson in how promising technology meets farm reality.

Study	Setting	What it found
Punjab Agricultural University (reported by Down To Earth)	Two-year field trial, rice and wheat, Ludhiana	Yields fell 13% in rice and 21.6% in wheat versus conventional nitrogen; grain nitrogen content also dropped
Frontiers in Sustainable Food Systems, 2025	Wheat, several nano urea products combined with basal nitrogen	Nano urea improved nutrient efficiency, but yields stayed below the full recommended fertiliser dose
Bangladesh Rice Journal	Boro rice, six zones, two seasons	Yield maintained with up to one-third less urea
Mysore J. Agric. Sci., 2025	Fodder maize, Mandya, kharif 2022 and 2023	Reported better yield and returns with reduced conventional nitrogen plus nano urea sprays

Reading the pattern

Two patterns stand out.

First, results are best when nano urea is added to a reduced dose of conventional

fertiliser, not used as a full substitute. The Frontiers wheat study concluded that matching conventional yields likely needs an optimised basal nitrogen level alongside the spray.

Second, independent trials sometimes disagree sharply with company claims. The PAU team noted that the cost of the nano formulation was roughly ten times that of granular urea, and that the yield decline grew in the second year. They called for 5–7 years of field evaluation before recommending it for rice and wheat. A parliamentary report also asked for close audit of field trials, and an audit by the Department of Fertilisers reportedly found a 25–50% variation in the nitrogen saving achieved (Down To Earth).

Why such different results?

Several plausible reasons exist, and scientists are still sorting them out:

- **Arithmetic of nitrogen.** A cereal crop takes up many kilograms of nitrogen per hectare. A small volume of foliar spray cannot easily supply that much, so some basal fertiliser is still needed.
- **Weather and timing.** Foliar sprays depend on leaf condition, humidity, rain and growth stage.
- **Trial design.** Studies differ in dose, crop, soil nitrogen status, and whether nano urea replaces or supplements conventional urea.
- **Soil nitrogen reserves.** In soils already rich in nutrients, almost any change looks harmless in the short run, which can mask long-term effects.

The lesson is not that nano-fertilisers fail. It is that claims must be tested crop by crop, soil by soil, and over several seasons.

6. Limitations and Risks: What the Hype Leaves Out

6.1 Agronomic limits

- **Inconsistent performance.** Soil composition, climate and the crop itself all change how a nano-fertiliser behaves (Buthelezi et al., 2025). A result from one trial seldom transfers cleanly to another.
- **Clumping.** Nanoparticles can aggregate, lose their nanoscale properties and become unavailable to plants (Madlala et al., 2024).
- **Mass balance.** Crops need nutrients in kilograms per hectare, especially nitrogen, phosphorus and potassium. Milligram-scale doses can help with micronutrients, but cannot fully feed a high-yielding cereal on their own.

- **Grain quality.** The PAU trial reported lower grain nitrogen content, which is linked to protein, a concern for staple foods.

6.2 Soil and ecosystem risks

What happens to nanoparticles after the crop is harvested is still poorly understood. Reviews raise several concerns:

- **Accumulation.** Repeated applications may build up nanoparticles in soil, and heavy use has been linked to cumulative pollution in both land and water (Buthelezi et al., 2025).
- **Soil microbes.** Nanoparticles can help or harm soil microbial communities, depending on type, dose and soil. A 2025 review notes that they can alter microbial dynamics and impair essential soil functions (Springer review, 2025).
- **Soil animals.** Zhang et al. (2026) flag possible effects on soil fauna such as earthworms, alongside accumulation in soil.
- **Metal-based particles.** Silver, copper, zinc and similar nanoparticles are the most worrying because they can be toxic at higher doses. Nutrient-based particles such as nano urea are generally considered less worrying than metal particles, but they are not free of unknowns.

These are mostly potential risks flagged by reviews and laboratory work. Long-term field evidence of harm is limited, but long-term field evidence of safety is also limited. That gap is the problem.

6.3 Economic and social limits

- **Cost.** Production costs and farmer adoption are listed among the key barriers to wider use (Gupta et al., 2025). If a product is costly and delivers only partial substitution, farmers may pay more without gaining.
- **Trust.** Disappointing early trials can damage farmers' confidence in an entire technology.
- **Access.** If supply sits with a few large manufacturers, smallholders may have little choice or bargaining power.
- **Subsidy risk.** Where subsidies back a product before independent evidence is in, public money may go to something unproven. One policy commentary argues that subsidy support should follow proof, not precede it.

6.4 What we do not know yet

The key knowledge gaps are long-term (multi-year) field effects on soil carbon, microbial diversity and soil animals; how particles transform in different soils; and realistic exposure levels for workers and the wider environment. Until these gaps close, nano-fertilisers are best seen as a promising tool still under evaluation, not a settled solution.

7. Rules and Safeguards: Regulation Is Catching Up

Nano-fertilisers do not fit neatly into old fertiliser rules, which were written for bulk products. Regulators are now adapting, and India is the most closely watched case.

India's 2026 reset

In March 2026, India notified 14 nano-fertiliser products under the Fertiliser (Inorganic, Organic or Mixed) Control Order, allowing their manufacture and sale for two years. A key requirement is validation that the products really are at the nanoscale (Global Agriculture).

A related amendment tightens the process. It strengthens requirements for biosafety testing, field trials, product approval and farmer guidance. Approval is product-specific rather than company-wide, so each formulation must be evaluated on its own. The recommended package of practice is to combine 75% of the conventional fertiliser dose with 25% nano fertiliser, based on positive trial outcomes (Global Agriculture).

This 75:25 approach matches what the field evidence suggests: nano-fertilisers as a partner to conventional inputs, not a full replacement.

The wider picture

Course material on biosafety notes that nano-fertilisers have moved through India's fertiliser-control route, while nano-pesticides remain in a more case-by-case policy space, and that the EU generally applies a more restrictive approach with detailed documentation and environmental review (Agridots). Regulation worldwide is still catching up with innovation.

Safe-by-design: what good practice looks like

Researchers and regulators increasingly point to a common set of practices.

1. **Characterise the product.** Report particle size distribution, surface area and charge, not just the label "nano".
2. **Test in real soils.** Trials should run for several seasons across different soil types and crops.

3. **Independent evaluation.** Data should come from public institutions, not only the manufacturer.
4. **Design for safety.** Prefer biodegradable carriers and nutrient-based particles that dissolve into ions plants use, rather than persistent metal particles. The 2025 review by Gupta and colleagues calls for biodegradable, sustainable nano-fertilisers with clear regulatory frameworks.
5. **Label clearly.** Products should state nanomaterial content, dose, method of application and handling precautions.
6. **Monitor after release.** Track soil carbon, microbial diversity and nutrient balance in fields where products are used repeatedly.

8. The Way Forward: A Practical Guide

Nano-inputs work best as one tool inside a sound soil-fertility plan. Building soil organic matter, rotating legumes, testing soil, balancing nutrients and applying fertiliser at the right time, place and rate all come first. Nano products can add value on top, but they cannot fix a poorly managed soil.

For farmers

- **Test before you trust.** Try a new product on a small strip beside your usual practice, so you can compare yields and costs directly.
- **Think partner, not replacement.** The best-supported approach so far is to reduce conventional fertiliser modestly and add the nano product, in line with the 75:25 guidance in India.
- **Do the sums.** Compare cost per hectare, not cost per bottle or bag.
- **Check approval and labels.** Buy only products notified under national fertiliser rules, and follow the recommended dose, timing and crop stage.
- **Protect the soil.** Keep adding organic matter, and watch for any slow decline in yield, grain quality or soil health over several seasons.

For researchers

- Run multi-year, multi-location trials with full conventional-dose controls and a reduced-dose comparison.
- Measure what happens to soil carbon, microbial communities and soil animals, not just yield.

- Publish particle characterisation and raw data so results can be compared.
- Develop low-cost, biodegradable carriers and field-ready nano-sensors suited to smallholders.

For policymakers

- Make independent efficacy and safety data a precondition for subsidy support.
- Keep approvals product-specific and time-limited, as India's 2026 notification does, and renew only on evidence.
- Fund long-term monitoring of fields where nano-products are used repeatedly.
- Invest in farmer advisory services so that adoption rests on advice rather than advertising.

What to watch next

The next two or three years will be informative. India's notified products are valid for two years, so the evidence gathered in that window will shape the next round of decisions. Meanwhile, research is moving toward nano-biofertilisers that combine beneficial microbes with nanocarriers, and toward sensor-guided precision systems. Both are early-stage, and both will need the same discipline: honest field testing over several seasons.

9. Conclusion and Key Takeaways

Nanotechnology can make fertiliser work harder, but it is a supplement to good soil management, not a shortcut around it. The science is promising, the commercial record is mixed, and the long-term soil effects are still being studied.

1. **Real potential.** Reviews report efficiency gains of up to about 30%, and a 2024 meta-analysis of 8,585 paired observations found average yield gains of 22.8%.
2. **Partner, not replacement.** The best field results come from combining nano products with a reduced dose of conventional fertiliser.
3. **Claims need independent proof.** Indian field trials ranged from yield maintenance to double-digit yield losses, depending on crop, design and product.
4. **Soil risks are unresolved.** Accumulation, microbial effects and impacts on soil animals need multi-year field studies.
5. **Regulation is tightening.** India's 2026 rules demand nano-scale validation, product-specific approval and trial evidence.
6. **Soil health comes first.** Organic matter, balanced nutrition and good agronomy remain the foundation of lasting fertility.

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Volume: 06 Issue No: 10

APPLICATION OF REMOTE SENSING AND SENSOR TECHNOLOGIES FOR REAL-TIME SOIL MOISTURE MONITORING

Article ID: AG-VO6-I10-85

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Introduction

Every farmer knows the feeling of kneeling in a field, pushing a hand into the earth, and guessing whether the crop needs water today or can wait until tomorrow. For centuries that guess, made by touch, colour and experience, was the only soil moisture meter available. Yet the answer matters enormously. Too little water and roots wilt, flowers drop and yields collapse; too much and nutrients wash away, roots suffocate and precious irrigation water is wasted. Soil moisture is the quiet hinge on which crop growth, groundwater recharge, flood generation and even local weather all turn (Seneviratne et al., 2010).

The difficulty is that soil moisture varies at a bewildering range of scales. It can change within a few metres across a single field because of differences in texture, slope and roots, and it can change within hours after a shower or an irrigation round. A single measurement in one corner of a farm says little about the rest. Over the last two decades, two families of technology have begun to solve this problem together: remote sensing, which observes the soil from a distance using satellites, aircraft and drones, and sensor technologies, which sit in the soil itself and report back continuously. This article explains, in plain language, how each works and how, combined, they are bringing real-time soil moisture information within reach of ordinary farmers.

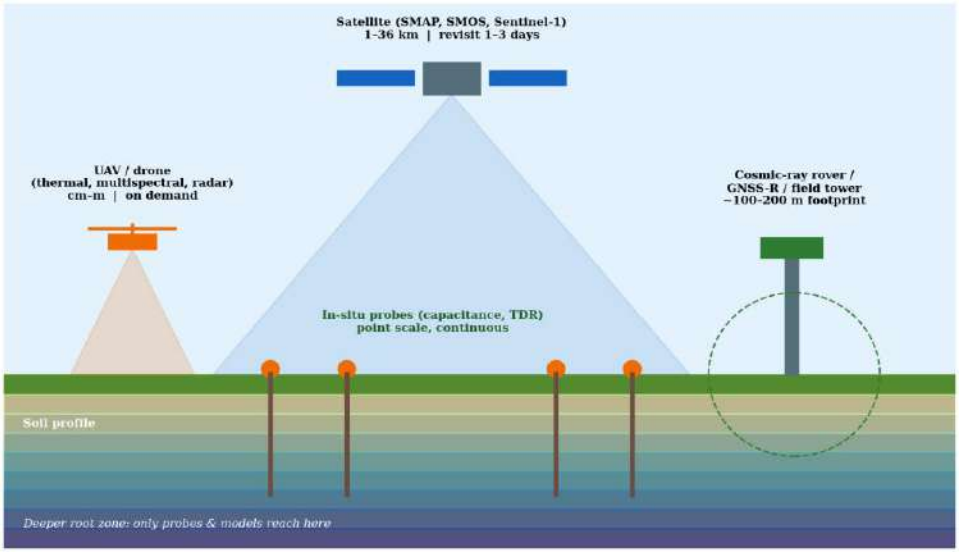


Figure 1. Soil moisture can be observed at several scales, from satellites to probes buried in the root zone. Note. Schematic created by the author; concept adapted from Babaeian et al. (2019) and Ochsner et al. (2013).

Why Soil Moisture Deserves Constant Attention

Soil moisture is only a tiny fraction of the planet's fresh water, but its influence is far out of proportion to its volume. It decides how much rainfall soaks in and how much runs off, how much energy a landscape sends back to the atmosphere as heat or as evaporation, and whether a seedling germinates or fails (Vereecken et al., 2008). Prolonged dry spells in the root zone are one of the earliest warnings of agricultural drought, usually appearing weeks before the crops themselves show visible stress.

For irrigation management the value is even more direct. Agriculture is the largest user of fresh water in most countries, and a great deal of it is applied on fixed calendars rather than according to what the crop actually needs. Knowing the real water status of the root zone allows irrigation to be timed and sized to match demand, which saves water, energy and labour while protecting yield. Reliable large-scale moisture records are also valuable to insurers, planners and flood forecasters, which is why the topic has attracted so much scientific attention (Ochsner et al., 2013).

Seeing Moisture from Space: The Microwave Advantage

Satellites cannot dig into the ground, but they can exploit a neat physical trick. Dry soil and liquid water interact very differently with microwaves, the long-wavelength radiation that

passes through clouds and works day and night. Water has a very high dielectric constant (roughly 80) compared with dry mineral soil (about 3 to 5), so even a modest increase in soil wetness produces a clear change in the microwave signal that returns to a sensor. Satellites measure this change in two ways: passively, by listening to the natural microwave glow of the Earth's surface, or actively, by sending out radar pulses and measuring the echo (Mohanty et al., 2017).

The first dedicated soil moisture missions chose low-frequency L-band microwaves because they penetrate vegetation reasonably well. The European Space Agency's Soil Moisture and Ocean Salinity (SMOS) satellite, launched in 2009, carries a novel interferometric radiometer and was the first mission built specifically to map global soil moisture and ocean salinity (Kerr et al., 2010). NASA's Soil Moisture Active Passive (SMAP) mission followed in 2015 with a large rotating antenna and a stated goal of retrieving surface soil moisture to within about 0.04 m^3/m^3 of accuracy every two to three days (Entekhabi et al., 2010). Alongside them, the scatterometers on the MetOp satellites provide a long, consistent radar record of surface wetness that feeds into merged global datasets (Dorigo et al., 2017).

These instruments see only the top few centimetres of soil, and their pixels are coarse, tens of kilometres across. Radar from the Sentinel-1 satellites, which carry a C-band synthetic aperture radar, offers a sharper view. Researchers have shown that Sentinel-1 data can be converted into soil moisture maps at about 1 km resolution, though dense crops, rough surfaces and steep terrain still complicate the retrievals (Bauer-Marschallinger et al., 2019). Merging many sensors has also produced a continuous multi-decade record. The ESA Climate Change Initiative soil moisture product combines active and passive microwave data going back to 1978, giving climate scientists a long baseline for spotting trends and extremes (Dorigo et al., 2017).

Closer to the Ground: Drones, Towers and Cosmic Rays

Between the satellite and the soil probe lies a useful middle ground. Small drones fitted with thermal, multispectral or lightweight radar sensors can survey a farm in minutes at centimetre-scale detail, whenever the farmer chooses to fly. Because wet soil heats and cools more slowly than dry soil, thermal images taken at the right time of day reveal moisture patterns, and crop canopy temperature can flag water stress before leaves visibly wilt (Babaeian et al., 2019). The main trade-offs are flight permissions, battery life and the need for careful calibration against ground measurements.

A more surprising technique listens to cosmic rays. High-energy particles from space constantly strike the atmosphere and create fast neutrons. Hydrogen atoms, which in a field are found mostly in soil water, slow down and absorb these neutrons, so the neutron count near the ground falls as the soil gets wetter. A single detector on a pole, or on a vehicle driven across the landscape, can therefore estimate average soil moisture over an area a few hundred metres wide without touching the soil at all (Zreda et al., 2008, 2012). This intermediate footprint fits well between a point probe and a satellite pixel, which is exactly the scale at which many farm decisions are made.

A Quick Comparison of the Main Tools

Approach	Typical footprint / depth	Best used for
Satellite microwave (SMAP, SMOS, ASCAT)	9–40 km; top ~5 cm; revisit 1–3 days	Regional and national drought watch; climate records
Satellite radar (Sentinel-1 SAR)	~1 km or finer; top ~5 cm; revisit several days	District-level mapping and irrigated-area monitoring
Drones (thermal, multispectral, radar)	Centimetres to metres; surface and canopy	Field-scale stress maps on demand
Cosmic-ray neutron sensing	~130–240 m radius; top 10–30 cm	Average moisture of a field or small catchment
In-situ probes (TDR, capacitance)	Single point; any chosen depth	Irrigation scheduling and validation of satellites

Table 1. The main approaches to soil moisture monitoring, their typical footprint and where each is most useful. Note. Compiled by the author from Babaeian et al. (2019), Mohanty et al. (2017) and Ochsner et al. (2013).

Sensors in the Soil: Point Measurements You Can Trust

Remote sensing is powerful, but it needs a reference. That reference comes from sensors buried in the soil, which measure moisture directly at the depths where roots actually work. Three types dominate. Time domain reflectometry (TDR), introduced in the 1980s, sends an electromagnetic pulse along metal rods and times its return; because the travel time depends on the soil's dielectric constant, it gives an accurate estimate of water content (Topp et al., 1980). Capacitance probes use the same dielectric principle with a simpler circuit, which makes them

far cheaper and the usual choice for field networks. Tensiometers and related devices measure something different, the suction with which soil holds water, which tells how hard a plant must work to extract it.

No sensor is perfect. Capacitance probes are sensitive to salinity, temperature and poor soil contact, and generic factory calibrations can be off by several percentage points in clay-rich or saline soils. Good practice is therefore to check or recalibrate sensors against oven-dried soil samples from the same field, to install them at several depths in the main root zone (for example 10, 30 and 60 cm), and to place more than one station in fields that differ in soil type (Ochsner et al., 2013). When this care is taken, probe networks become the benchmark against which satellite products are tested, and international archives such as the International Soil Moisture Network now collect data from many such networks worldwide for exactly this purpose (Dorigo et al., 2011).

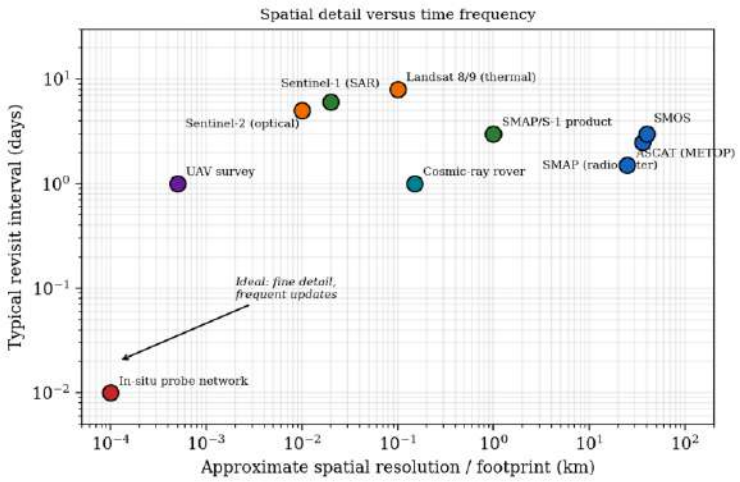


Figure 2. Approximate spatial detail and revisit time of soil moisture observation platforms. Note. Chart created by the author using typical values reported by Babaeian et al. (2019), Entekhabi et al. (2010), and Kerr et al. (2010); values are indicative only.

Going Real-Time: When Sensors Join the Internet

A buried probe that must be dug up and read with a handheld logger is useful, but not real time. The breakthrough has been combining low-cost sensors with low-power wireless communication. A modern sensor node is essentially a small microcontroller, a battery and a solar panel attached to several probes. It wakes every 15 to 60 minutes, takes a reading, sends it through a low-power radio link such as LoRa or through the mobile network to a gateway, and

returns to sleep. The gateway forwards the data to a cloud server where it is stored, plotted and compared with crop-specific thresholds.

Field trials of wireless soil moisture networks show that they can capture the patchiness of moisture across a landscape that a single logger would miss, and that the data can be delivered continuously without anyone visiting the site (Ochsner et al., 2013). From the server, the farmer can receive an SMS alert, check a phone dashboard, or let the system act on its own by switching a smart valve on a drip line when the moisture reading falls below a trigger level. Because only a few small numbers are transmitted per reading, even farms with weak mobile coverage can be connected.

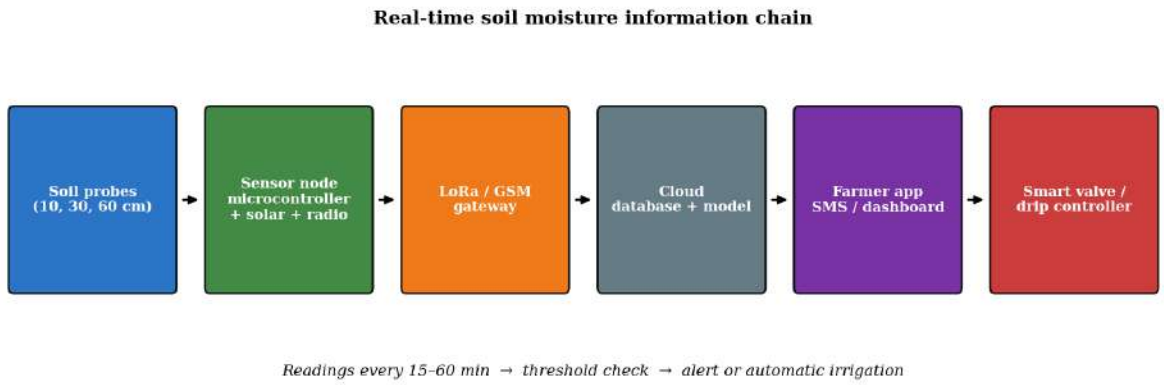


Figure 3. Typical information chain of a real-time sensor-based soil moisture and irrigation advisory system. Note. Diagram created by the author; system layout adapted from the networked monitoring approaches reviewed by Ochsner et al. (2013).

Stronger Together: Blending Satellites and Sensors

The real promise lies not in choosing between satellites and probes but in combining them. Satellites offer wide coverage and a consistent view across regions that have no instruments at all, while probes offer accuracy, depth and continuous time series at a few points. Scientists link the two in several ways. Ground networks are used to validate satellite products and correct their errors. Coarse satellite pixels are downscaled using finer data on terrain, vegetation and soil texture. Finally, both streams are fed into land surface and crop water models through a process called data assimilation, so that the model is continually nudged back towards reality (Mohanty et al., 2017; Peng et al., 2021).

The outcome is a practical estimate of root-zone moisture, the layer that actually matters to crops, even though satellites themselves only observe the surface. Figure 4 shows what such information looks like to a farmer. The trace rises sharply after rain or irrigation, then declines day by day as the crop and the atmosphere draw the water back out. Once the line approaches the stress threshold, an irrigation decision is triggered, and the next watering is sized to refill the root zone to field capacity rather than to flood it.

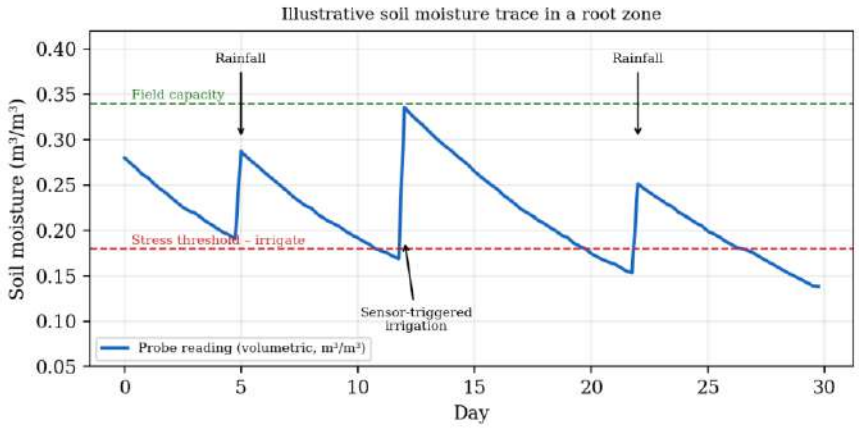


Figure 4. Illustrative soil moisture trace over 30 days showing rainfall, a threshold-triggered irrigation and the natural drying cycle. Note. Simulated data generated by the author for illustration only; not a field measurement.

Where This Makes a Difference

In irrigated agriculture, sensor-guided scheduling is the most immediate application. Watering only when the root zone falls to a set threshold, and only by the amount needed, cuts waste and prevents the waterlogging that damages roots and encourages disease. For rainfed farmers, satellite-derived moisture maps can inform sowing dates and provide early warnings of developing drought, giving time to adjust crop choices or arrange fodder and relief. Insurance schemes and government agencies can also use consistent regional moisture records to assess drought severity more transparently than rainfall data alone (Peng et al., 2021).

Beyond the farm, soil moisture observations improve flood forecasts, because a saturated catchment turns rain into runoff far faster than a dry one. They help climate scientists understand heatwaves, since dry soils lose the cooling effect of evaporation and amplify temperature extremes (Seneviratne et al., 2010). And they support catchment managers who must decide how to share limited water between towns, industry and agriculture.

Challenges on the Road

Real-time soil moisture monitoring is not yet effortless. Satellite pixels are still too coarse for individual small farms, and dense vegetation, rough terrain and frozen or very wet soils can degrade retrievals. Sensors can be damaged by tillage, rodents or lightning, drift over time, and need periodic maintenance. Wireless networks require power, connectivity and technical support, and the up-front cost of a full system may be out of reach for smallholders unless it is shared through cooperatives, farmer-producer organisations or extension services. Finally, data are only useful if they are translated into simple advice, such as a clear message on when and how much to irrigate, in the local language.

The Road Ahead

Several developments are narrowing these gaps. New radar missions and improved algorithms are steadily sharpening the resolution of satellite soil moisture, while cheaper sensors, better batteries and wider low-power networks are driving down the cost of in-field monitoring. Machine learning is being used to correct sensor errors, fill gaps and forecast moisture a few days ahead, and low-cost drone and smartphone-based tools are widening access to field-scale information. A key priority identified by the research community is to match product characteristics with what users really need, in terms of depth, resolution and timeliness (Peng et al., 2021).

For a farmer, the long-term vision is refreshingly simple: a phone message that says which plot needs water, how much, and when. Behind that single message will sit satellites orbiting hundreds of kilometres overhead, drones buzzing across the canopy, and small probes quietly listening in the dark soil. Together they turn the age-old guess in the field into an informed decision, and that is a real step toward growing more food with less water.

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Volume: 06 Issue No: 10

BIO-PROSPECTING OF AQUATIC PLANTS

Article ID: AG-VO6-I10-86

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Abstract

Bio-prospecting is a systematic and interdisciplinary approach that explores natural resources to identify bioactive compounds with significant applications in pharmaceuticals, agriculture, biotechnology, and environmental management. Aquatic plants, including macroalgae, microalgae, seagrasses, and freshwater species, represent a vast and underexplored reservoir of valuable biomolecules such as polysaccharides, carotenoids, flavonoids, and essential fatty acids. These organisms possess unique metabolic pathways that enable the production of diverse secondary metabolites with antimicrobial, antioxidant, antiviral, and anticancer properties, thereby playing a crucial role in novel drug discovery and sustainable product development. In addition, aquatic plants contribute to emerging solutions such as biofuel generation, bioremediation, and carbon sequestration. Despite their immense potential, bio-prospecting efforts are constrained by challenges including sustainability concerns, technological limitations, and ethical issues related to access and benefit sharing. Therefore, integrating traditional knowledge with advanced scientific techniques, while adhering to regulatory frameworks such as the Nagoya Protocol, is essential. Overall, bio-prospecting of aquatic plants holds considerable

promise for driving sustainable innovation, supporting environmental conservation, and enhancing global economic development.

DEFINITION OF BIO-PROSPECTING

- Bio-prospecting, also known as biodiversity prospecting, refers to the systematic search for bioactive compounds, genetic materials, and biochemical properties from natural sources, such as plants, animals, fungi, and microorganisms. The primary goal is to develop new pharmaceutical drugs, industrial enzymes, agricultural products, and environmental solutions.
- It involves interdisciplinary approaches combining biotechnology, microbiology, environmental science, pharmacology, and indigenous knowledge systems. Bio-prospecting often targets biodiversity-rich ecosystems such as tropical rainforests, marine environments, and extreme habitats (e.g., deep-sea vents, hot springs).

WHY IS IT NEEDED?

- The underlying aim of bioprospecting is to find new resources and products from nature that can be used by humans.
- Improving human health, through both medicine and better nutrition are key focal areas.
- It plays a dominant role in discovering leads for drug development, since existing/known compounds for developing drugs for human use are limited.
- A study showed that between 1983 and 2003, almost two thirds of anti-cancer agents being investigated as drug candidates were derived from natural products.
- Other related sectors, such as crop plant biotechnology, screen natural resources for useful traits, such as disease resistance.

PROCESS OF BIOPROSPECTING

Phase 1:

- On-site collection of samples

Phase 2:

- Isolation, characterization and culture of specific compounds

Phase 3:

- Screening for potential uses, such as pharmaceuticals or other uses

Phase 4:

- Product development and commercialization, including patenting, trails, sales and marketing

CONCEPT OF BIO-PROSPECTING

- Bio-prospecting is based on the idea that nature holds untapped biological resources that can lead to novel discoveries and innovations. It focuses on extracting, identifying, and utilizing bioactive compounds from living organisms for commercial and scientific purposes.
- The concept can be broken down into the following key aspects:

1. EXPLORATION OF BIOLOGICAL RESOURCES

- Scientists collect biological specimens from diverse ecosystems, including plants, fungi, marine organisms, and microorganisms.
- Extreme environments such as deserts, deep oceans, and hydrothermal vents are rich sources of novel bioactive molecules.



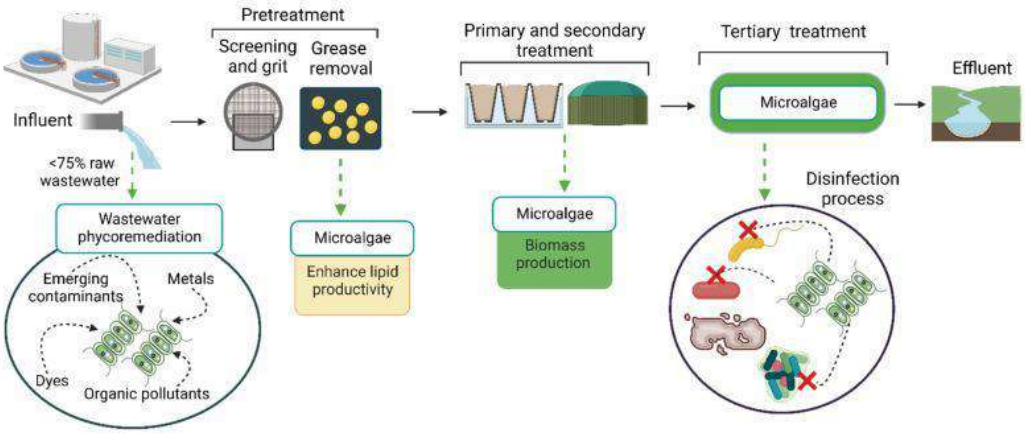
2. IDENTIFICATION AND SCREENING OF BIOACTIVE COMPOUNDS

- Extracts from biological samples undergo biochemical and pharmacological screening.
- Advanced techniques such as high-throughput screening, metabolomics, and genomics help in identifying potential applications.

3. APPLICATIONS OF BIO-PROSPECTING

- **Medical Industry:** Discovery of new antibiotics, anticancer drugs, and vaccines.
- **Agriculture:** Development of pest-resistant crops, biofertilizers, and plant growth enhancers.

- **Biotechnology and Industry:** Enzymes for biofuels, biodegradable plastics, and green chemistry.
- **Environmental Science:** Bio-remediation and sustainable waste management.



4. SUSTAINABLE AND ETHICAL CONSIDERATIONS

- **Conservation of Biodiversity:** Ensuring that natural resources are not overexploited.
- **Access and Benefit-Sharing (ABS):** Agreements under the **Nagoya Protocol** ensure fair sharing of benefits with indigenous communities.
- **Intellectual Property Rights:** Protection of discoveries through patents while preventing biopiracy (unauthorized use of genetic resources or traditional knowledge).

5. ROLE OF TRADITIONAL KNOWLEDGE

- Indigenous communities have long utilized plants and natural resources for medicinal and other purposes.
- Collaboration between scientists and local populations can enhance bio-prospecting while ensuring ethical benefit-sharing.

BIO-PROSPECTING OF AQUATIC PLANTS:

- Bio-prospecting of aquatic plants refers to the exploration and utilization of bioactive compounds, genetic material, and biochemical properties derived from freshwater, marine, and estuarine plants.
- These plants offer a vast and underexplored reservoir of potential compounds useful in pharmaceuticals, cosmetics, agriculture, and industrial applications.

IMPORTANCE OF AQUATIC PLANTS IN BIO-PROSPECTING

Aquatic plants, including seaweeds (macroalgae), microalgae, seagrasses, and floating or

submerged freshwater plants, have unique adaptations and secondary metabolites that make them valuable for various applications:

- **Pharmaceuticals:** Anti-inflammatory, antimicrobial, antiviral, antioxidant, and anticancer compounds.
- **Nutraceuticals:** Rich sources of vitamins, minerals, and bioactive compounds used in dietary supplements.
- **Cosmetics and Personal Care:** Anti-aging, moisturizing, and UV-protective compounds.
- **Agriculture:** Bio-fertilizers, biopesticides, and plant growth stimulators.
- **Biofuels:** Algae-derived bioethanol, biodiesel, and biogas as alternative energy sources.

TYPES OF AQUATIC PLANTS USED IN BIO-PROSPECTING

a) Macroalgae (Seaweeds)

Examples: Kelp (*Laminaria* spp.), Red algae (*Gracilaria* spp.), Brown algae (*Sargassum* spp.), Green algae (*Ulva* spp.).

Bioactive Compounds: Polysaccharides (alginate, carrageenan, fucoidan), polyphenols, sterols, and proteins.

Applications:

- **Pharmaceuticals:** Antiviral agents (fucoidan from brown algae), anticoagulants, and anticancer compounds.
- **Food Industry:** Hydrocolloids like agar and carrageenan used as thickeners and stabilizers.
- **Cosmetics:** Hydrating and anti-aging agents in skin care.

b) Microalgae

Examples: Spirulina (*Arthrospira* spp.), Chlorella (*Chlorella* spp.), Dunaliella (*Dunaliella salina*).

Bioactive Compounds: Carotenoids, chlorophyll, essential fatty acids, and proteins.

Applications:

- **Nutraceuticals:** Omega-3 fatty acids (DHA and EPA) for heart health.
- **Pharmaceuticals:** Antioxidants like astaxanthin and beta-carotene.
- **Biofuels:** Algal lipids used for biodiesel production.

c) Seagrasses

Examples: *Zostera marina, Thalassia testudinum, Halophila ovalis.*

Bioactive Compounds: Flavonoids, tannins, saponins, and phenolic acids.

Applications:

- **Medicinal Uses:** Anti-inflammatory and antibacterial properties.
- **Environmental Role:** Carbon sequestration, habitat for marine life, and biofiltration.

d) Freshwater Aquatic Plants

Examples: *Eichhornia crassipes* (Water Hyacinth), *Azolla* spp., *Hydrilla* spp.

Bioactive Compounds: Alkaloids, flavonoids, lignins, and glycosides.

Applications:

- **Water Treatment:** Phytoremediation to remove heavy metals and pollutants.
- **Agriculture:** Bio-fertilizers and soil conditioners.

METHODS OF BIO-PROSPECTING AQUATIC PLANTS

- **Field Sampling & Collection:** Identification and collection from marine and freshwater ecosystems.
- **Extraction of Bioactive Compounds:** Using solvents like ethanol, methanol, and water to extract secondary metabolites.
- **Biochemical and Pharmacological Screening:** Testing for antimicrobial, antioxidant, anticancer, and other therapeutic activities.
- **Genomic & Metagenomic Approaches:** Identifying genetic potential for producing bioactive compounds.
- **Bioprocessing & Commercialization:** Large-scale cultivation (e.g., algal bioreactors) for sustainable production.

CHALLENGES AND ETHICAL CONSIDERATIONS

- **Sustainability Concerns:** Overharvesting of aquatic plants can disrupt ecosystems.
- **Legal and Regulatory Frameworks:** Compliance with international treaties like the Nagoya Protocol on Access and Benefit-Sharing.
- **Technological Barriers:** Developing cost-effective and scalable bioprocessing techniques.

- **Biopiracy Risks:** Ensuring fair compensation for indigenous and local knowledge contributions.

FUTURE PROSPECTS AND APPLICATIONS

- **Marine Pharmaceuticals:** Increased exploration of deep-sea flora for novel drug discovery.
- **Climate Change Mitigation:** Carbon sequestration potential of seaweeds.
- **Biodegradable Plastics:** Algae-based sustainable packaging materials.
- **Smart Agriculture:** Algae-based fertilizers and soil enhancers.

Conclusion

- Bio-prospecting is a crucial field that bridges biodiversity conservation with technological advancement. It has immense potential in healthcare, agriculture, industry, and environmental sustainability.
- However, ethical considerations, legal frameworks, and sustainable practices must be followed to ensure that bio-prospecting benefits both humanity and nature without causing harm to ecosystems or local communities.
- Bio-prospecting of aquatic plants is a promising field with vast potential in healthcare, food, cosmetics, and sustainable industry.
- By adopting ethical and sustainable practices, bio-prospecting can contribute to global health, environmental conservation, and economic development.

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Volume: 06 Issue No: 10

ROLE OF TRAINING & PRUNING SYSTEM IN LOGAN BERRIES

Article ID: AG-VO6-I10-87

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Introduction

Loganberries are usually planted about 3.7 m apart and are cut back as for raspberries. The main training systems are the open fan, the 'modified open fan' and the 'rope' or 'arch' method. The two latter systems make use of practically all cane growth whereas half of this may have to be sacrificed with the open fan resulting in much crop loss. But the open fan method is more convenient where space is limited, as the plants can be put in much nearer together only 2.5cm -3m apart.



Open fan

Fix wires at about 60 cm, 1m, 1.5 m and 2m from ground level to stout end and middle posts 2.5 m long, which have been sunk 60cminto the ground. Arrange the fruiting canes fanwise on the first wires, with a gap in the centre. Lead the new canes up through this gap and tie temporarily to the top wire. After harvesting cut the fruited canes right out at the base and tie the new ones into replace them.

Modified Open fan

Fix wires at 60cm, 90cm, 1.25m, 1.5m and 2m from ground level. Train the fruiting canes to more or less their full length, left and right of centre along the first four wires, while the top wire again takes the new ones.

Rope or Arch

Train all fruiting canes in one direction, and all new ones in the opposite direction. When more than one stool is planted, arrange the training so that the fruiting canes of one stool always meet the fruiting canes of its neighbour. Separation of fruiting from non-fruiting wood makes picking and pruning much easier and reduces the risk of cane spot fungus, the spores of which are washed from old to new canes.

Modern loganberry plants can produce a dozen or more canes each season, all of which you can tie in practically full length with the rope and modified open fan systems, thereby ensuring the maximum crop which may be 4.5 – 5 kg per plant when the plants are fully established. In all cases you need to sink stout posts 2.5 m long, to a depth of 60cm.

Volume: 06 Issue No: 10

CLIMATE VARIABILITY IN JASMINE CULTIVATION IN INDIA

Article ID: AG-VO6-I10-88

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Introduction

Jasmine is an important commercial flower crop in Tamil Nadu and plays a significant role in the agricultural economy of Madurai district. Madurai Malli is recognised for its distinctive fragrance and quality and provides income and employment opportunities to farming households. However, fluctuations in temperature, rainfall, relative humidity and wind speed may influence flowering, flower retention, productivity and quality. The highly perishable nature of jasmine also exposes farmers to market-price fluctuations and income instability.

Jasmine is one of the oldest fragrant flowers cultivated in India and is among the most common loose flowers in the Indian commercial flower Jasmine as a fragrant flower plays an important role in perfume and cosmetics Industry. It is highly cultivated in south India states like Tamil Nadu, Andhra Pradesh and Karnataka, where it has significant value in religious and cultural activities during festivals and weddings. Jasmine is considered as “Queen of flowers”, often has high volatility in price due to different factors like supply, market arrival and climate, and demand factors like festivals and wedding days. The plant belongs to the Oleaceae family and has about 200 species worldwide, of which 40 species are reported from India. Of the total species, three commonly cultivated jasmine species in Tamil Nadu are *Jasminum sambac*, *Jasminum auriculatum* , *Jasminum grandiflorum* and the flower known as Madurai Malli is mostly of *J.sambac* species. Jasmine is mainly cultivated for its highly fragrant white flowers used for decoration, offering, garlands, bouquets, perfumes, cosmetics, soap, and incense

production. Thus, apart from economic contributions through flower sales, the plant provides value addition and export benefits. Jasmine flowers play a significant role in religious and cultural traditions of Indian people. Jasmine is one of the oldest fragrant flowers playing a significant role in perfume and cosmetics industry, and act as good business crop. So, in recent years jasmine price variation is high in markets were reported in news.

Status of jasmine cultivation in Tamil Nadu, India

Tamil Nadu is an important state in India in terms of jasmine cultivation. In fact, this region is one of the significant producers of fragrant loose flowers in the country. Jasmine is a high-profile commercial floral crop in Tamil Nadu. It plays a special role in religious rites, weddings, hair decoration, garlands, and the loose-flower trade. According to Tamil Nadu's Agriculture Budget 2025-26, "Jasmine is grown in about 42 thousand acres in Tamil Nadu with an annual production of about two lakh tonnes". The main jasmine-growing districts are Madurai, Dharmapuri, Thiruvallur, Salem, Dindigul, Thiruvannamalai, Krishnagiri, and Erode. Most of Tamil Nadu's jasmine production is sold as loose flowers. However, there are also significant export potentials for specific jasmine varieties, linked to the perfume and essential oil industries .

Historical figures can also be used to illustrate the growth of jasmine cultivation. According to statistics gathered by the Directorate of Horticulture and Plantation Crops, the area harvested for this crop saw an increase from 5,732 hectares in 1997-98 to 15,581 hectares in 2011-12, while production rose from 43,713 tonnes to 120,750 tonnes. For the Madurai region, in particular, the area harvested for jasmine grew from 551 hectares in 2000-01 to 1,429 hectares in 2012-13, and production increased from 4,270 tonnes to 13,047 tonnes. This data can be used to show the growing commercial importance of jasmine cultivation in Tamil Nadu in general, and the Madurai region in particular.

Jasmine cultivation in Madurai

Madurai has a special place in jasmine production because it is one of the major jasmine-growing districts of Tamil Nadu and because the crop is sufficiently concentrated there for economic and market-structure studies to treat the district as a dominant production zone. The jasmine cultivar grown in Madurai and adjoining belts has a Geographical Indication identity, underscoring its place-based reputation and market distinctiveness. This place specificity matters

because crop value in floriculture depends not only on yield, but also on fragrance, timing, quality, and buyer recognition.

Madurai Malli got its GI-tag for its aromatic fragrance and thick petals which is responsible for its longer shelf life. The heavy fragrance of the flower is a result of the accumulation of alkaloids such as ‘jasmone’ and ‘alpha terpineol’. These alkaloids accumulate owing to the topography of the Madurai region where the flowers are harvested. The heavy fragrance of the flower is a result of the accumulation of alkaloids such as ‘jasmone’ and ‘alpha terpineol’. These alkaloids accumulate owing to the topography of the Madurai region where the flowers are harvested. Jasmine in Madurai is a high-value floriculture crop, whose economic returns are sensitive to biological, seasonal and daily price market forces.

Crop characteristics

Jasmine is a perennial commercial flower crop that provides repeated or near year-round harvests for one reasonit is attractive to small and marginal farmers. In addition, it is a sun-loving crop that thrives in warm humid climates and grows best in well-drained sandy loams and red loams with pH around 6.5-7.5. Typically, recommended planting is from June to August with rooted cuttings transplanted into prepared pits and irrigation supplied at regular intervals. A key production characteristic is that jasmine flowering is seasonal even within a perennial system. Studies note peak and lean productive periods with abundant flowering in some Tamil months and lower output in rainy periods, when prices tend to rise. Off-season management is therefore economically important and regression work in Jasminum sambac indicates that staggered pruning can be used to enhance yield during the December-March off-season. This biology-market linkage is critical to Madurai jasmine economics because synchronization of flowering with peak market price is crucial in flower farming .

Climate Variability and its Relationship with Jasmine Production and Farm Economics

Climate variability has an important relationship with the biological performance and economic viability of jasmine cultivation, since jasmine is a commercial loose-flower crop that returns on its continuous flowering, flower-bud development, flower quality, marketable output and the costs incurred in production. Temperature is one of the major climatic factors influencing jasmine growth and flowering. Research on Jasminum sambac has demonstrated that temperature and photothermal conditions influence flower development, flowering duration and flower characteristics, indicating that jasmine responds significantly to its thermal environment.

Experimental evidence has shown that favourable warm temperatures can improve flowering performance; therefore, an increase in temperature should not automatically be interpreted as harmful to jasmine production. Instead, the effect of temperature is likely to depend on the cultivar and the range of temperatures experienced by the crop. A recent study on white jasmine also reported that air temperature and humidity influenced bud emergence and the duration required for large flower buds to develop towards anthesis, demonstrating the direct relationship between climatic conditions and flowering phenology .

Rainfall and moisture conditions are equally important, although their effects cannot be understood solely from the total amount of annual precipitation. The timing, distribution and intensity of rainfall influence soil-moisture availability and consequently the amount of irrigation required by farmers. Jasmine cultivation requires adequate moisture, while cultivation recommendations emphasize warm conditions, sunny weather and irrigation according to prevailing weather conditions. Jasmine-specific research on Ramanathapuram Gundumalli has further demonstrated that soil-moisture depletion, irrigation frequency and the quantity of irrigation water significantly influence growth, physiological performance and flower-yield attributes, confirming the importance of root-zone moisture for successful jasmine production. Thus, even when the long-term trend in total rainfall is statistically insignificant, irregular rainfall distribution and changes in soil moisture can still affect production through increased water stress or greater dependence on irrigation. Humidity, sunlight and other atmospheric conditions also contribute to the microclimatic environment in which jasmine flowers develop. Evidence from jasmine flowering phenology shows that temperature, humidity, rainfall and sunlight intensity collectively occur alongside different stages of bud development and anthesis. Solar radiation is particularly important because it provides the energy required for photosynthesis and supports carbohydrate production necessary for plant growth and reproductive development. Studies of jasmine flower development have also identified physiological and metabolic changes across different developmental stages, while research on flower development and aroma formation confirms that the economic value of jasmine is closely connected with developmental processes and flower characteristics.

Problem of Jasmine Cultivation

Jasmine is a climate sensitive crop so changes in temperature, rainfall, humidity, sunlight and soil moisture can potentially alter flowering intensity, the timing of bud development,

marketable flower production and irrigation requirements. Climate variability may therefore affect farmers through both a production pathway, by influencing the quantity and quality of marketable flowers, and a cost pathway, by changing requirements for irrigation, labour and other management operations. Consequently, changes in climatic conditions can influence gross returns, production costs and ultimately net farm income. Overall, the climatic relationships observed creates an economic impact on farmers.

Government Policy and Practical Implications

First, extension agencies should promote location-specific climate advisories for jasmine farmers, particularly concerning temperature extremes, rainfall timing, humidity-related pest and disease risks and wind events. Advisories should be linked to practical decisions such as irrigation scheduling, drainage maintenance, pest surveillance, harvesting and flower handling.

Second, greater attention should be given to efficient water management. Irrigation facilities, water-saving technologies, soil-moisture conservation and drainage improvement can help farmers manage both moisture deficit and excess wetness. Support should be directed especially towards smallholders who may face difficulties in investing in water-management infrastructure.Third, farmer-oriented pest and disease management programmes should be strengthened. Since pest and disease management was the most widely adopted adaptation practice, extension interventions can build on existing farmer experience while improving diagnosis, timing and safe input use.

Fourth, market information systems should provide timely and reliable information on daily jasmine prices, market arrivals, festival demand and alternative markets. Farmer groups and collective marketing arrangements may improve bargaining power and reduce dependence on individual intermediaries. Such measures cannot eliminate price volatility, but they may reduce the information disadvantage faced by growers.

Finally, future research should use longer and more frequent datasets, preferably monthly or daily climate and production records, to examine extreme events, rainfall timing, flowering cycles and nonlinear temperature responses. Longer price series would also permit a more reliable analysis of seasonality, structural breaks and asymmetric price volatility. The present findings provide a useful baseline for such future work, but the conclusions should be interpreted within the selected blocks, the available data periods and the limitations of farmer-reported information.

Volume: 06 Issue No: 10

A WORKER IS A CREATOR: INTERNATIONAL LABOURS DAY

Article ID: AG-VO6-I10-89

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Introduction

International labor day celebrated on May 1st, honors workers contributions and advocates for rights, stemming from the 19th – century struggle for an eight-hour workday. Known as May day, it is a public holiday in over 80 countries-featuring parades and rallies-rooted in the1886 Haymarket affair. Promoting solidarity for better working conditions.

Origin and History:-

Originated from the late 19th century American labour movement, specifically the nationwide strikes for an eight-hour workday that began on May1,1886.

The movement peaked with the Haymarket affair in Chicago in 1886, where police killed protesting workers, leading to violent riots. It was designated an international day by an **International Socialist Conference in 1886.**

- **1886 Haymarket Affair** : Following a strike in Chicago, a bombing on May 4th at Haymarket square resulted in police shooting unarmed workers, becoming a pivotal movement in the struggle for workers rights.
- **The 8-Hour Movement**: The day originated from the late 19th –century American labour movement, specifically demanding a standard 8-Hour workday (8 hours for work, 8 hours for recreation, 8 hours for rest).

- **Recognition:** In 1889, the International Socialist Congress in Paris declared May 1st an International workers day to commemorate these struggles.
- **Significance:** It commemorates the sacrifice made for better working conditions, fair wages, and shorter working hours (eight-hour day).
- **Declarati**on: In 1889, a federation of socialist groups and trade unions met in Paris and designated May 1st as a worldwide demonstration day.
- **Global Observation**: Known as May Day as or International Labours Day, it is now a public holiday in over 80 countries.
- **India's 1st Celebration :** Held in 1923 in Chennai by the Labour Kisan Party of Hindustan. S

Commonly Observed 2025 Theme: the 2025 theme often centers on "Social Justice and Decent work " and "Safety and Health of Workers," emphasizing modern challenges like fair wages, digital transformation, and Occupational Safety and Health (OSH).

Importance of labours day:

Labour is the fundamental, active, and indispensable human factor in production, transforming raw materials into goods and services. It **drives economic growth, fosters innovation, generates individual income, and builds essential infrastructure.** Beyond economics, labour ensures social stability and facilitates human capital development.

Major 5 key points on the importance of labour:

- **Primary Factor of Production:**

  Labour is the active agent drives all production processes, converting raw materials into finished, usable goods and services, without human effort, land and capital remain inactive.
- **Drives Economic Growth &Productivity:**

  Labour is essential for economic development and industrialization, with higher skilled labour leading to increased productivity and overall national prosperity.
- **Generates Income &Improves Living Standards:**

  Labour is the main source of income for individuals, enabling consumption and providing the means to improve one's quality of life.
- **Infrastructure & Innovation:**

  Labour is responsible for building and maintaining crucial infrastructure (roads, bridges,

buildings) and fosters innovation and creativity, particularly in knowledge-based sectors.

- **Promotes Social Stability & Cohesion:**

  Productive labour reduces poverty, decreases income inequality, and promotes social stability by providing employment opportunities and reducing social unrest.

International labour Day or Antarrashtriya Shramik Diwas (May1), honors the Indian working class, promotes awareness of labour rights, and advocates for fair wages, safe working conditions, and dignity for all workers, including those in the informal sector. It recognizes their role in nation building and highlights the ongoing need for social justice and legal reforms.

Conclusion

The day traces its roots to events like the Haymarket Affair, which become a symbol of workers resistance and unity. Today, it continues to highlight issues such as worker rights, social justice, and economic equality. International Workers Day is both a celebration of progress made and a call to action. It reminds societies, governments, and organizations that the fight for works rights is far from over-and that collective effort remains essential to building a more equitable future.

Volume: 06 Issue No: 10

THE BLACK GARLIC

Article ID: AG-VO6-I10-90

***Mansi Badhani and Komal Chauhan**

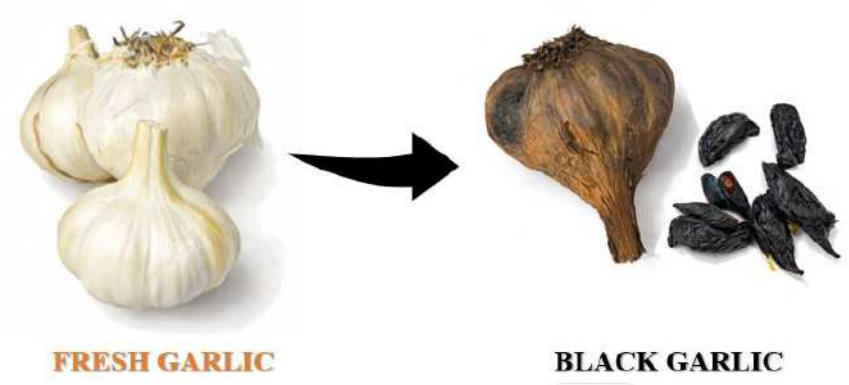
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Introduction

Garlic (*Allium sativum* L.) has been valued for centuries not only as a culinary ingredient but also as a potent functional food. From traditional remedies to modern nutrition, it is widely recognized for its antimicrobial, cardioprotective, anti-inflammatory, and immunomodulatory effects. These health benefits are largely attributed to sulfur-containing compounds, particularly allicin, which is formed when garlic cloves are crushed or chopped.

However, despite its therapeutic potential, the regular consumption of raw garlic is limited by its strong pungency, persistent odor, and gastrointestinal discomfort or intolerance in sensitive individuals. Moreover, allicin is chemically unstable and degrades rapidly during storage, reducing its bioactivity.



These constraints have led to growing interest in processing strategies which enhances garlic's stability, bioavailability, and consumer acceptability. Among these, black garlic has emerged as a

promising derivative which is produced through controlled thermal aging of whole garlic bulbs under high temperature and humidity. This process results in series of physicochemical and biochemical modifications, including a softened texture, dark color, mild sweet–umami flavor, and formation of more stable bioactive compounds. Therefore, black garlic represents a unique convergence of traditional knowledge and modern food science, with both improved palatability and enhanced health-promoting properties

Process of transformation

The transformation of fresh garlic into black garlic is primarily driven by controlled heat processing. Whole garlic bulbs are aged under regulated conditions, typically at temperatures between 60 and 90°C and relative humidity levels of 70–90% over a period of 2–6 weeks. Temperature, humidity, and duration work synergistically to influence reaction kinetics, moisture retention, and the stability of bioactive compounds. This determines the sensory and functional quality of the final product. Lower temperatures combined with longer aging durations favor gradual chemical transformations, preserving heat-sensitive bioactives while allowing the steady accumulation of stable organosulfur compounds. In contrast, higher temperatures accelerate these reactions, intensifying browning and flavor development through enhanced mallard reactions. But sometimes this may lead to partial degradation of thermolabile bioactives. Humidity plays an equal crucial role by preventing excessive drying and ensuring uniform heat penetration through the garlic bulbs. This helps maintain the soft jelly-like texture that characterizes black garlic. The duration of processing further determines the extent of sweetness, color development and bioactive enrichment.

Compositional changes

Thermal aging refine both sensory characteristics and functional properties of the garlic. These transformations affect carbohydrates, lipids, amino acids and bioactive compounds.

In fresh garlic, carbohydrates are mainly present as fructans. These undergo progressive breakdown and generates mono- and disaccharides, particularly glucose and fructose. As a result, the reducing sugar content of black garlic increases significantly, providing the characteristic sweetness of black garlic and fueling mallard reactions responsible for its dark color and rich flavor.

Although present in lower concentration, garlic lipids also play important role in flavor development. Thermal processing induces hydrolytic and oxidative changes, producing aroma-

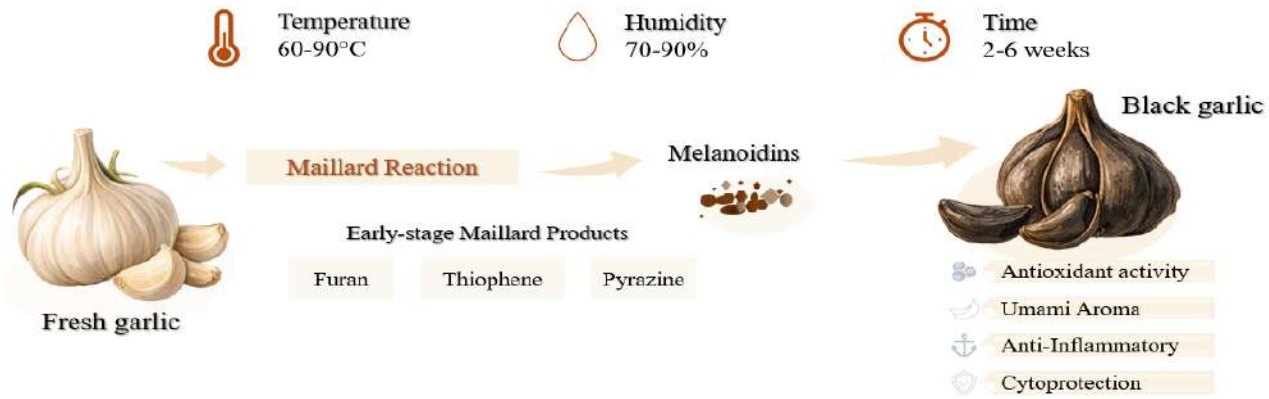
active compounds such as aldehydes, ketones, alcohols, and lactones. These interact with mallard intermediates, collectively shaping the complex sensory profile associated with black garlic.

Similarly, proteins and free amino acids, including sulfur-containing and aromatic amino acids, participate in Maillard reactions. While some branched-chain amino acids increase under specific conditions, others, particularly sulfur-containing ones, decline, influencing both antioxidant potential and flavor complexity. These contribute to the soft, jelly-like texture that distinguishes black garlic from fresh counterpart.

In addition, thermal processing also affects the polyphenolic content of garlic. Black garlic consistently exhibits higher total phenolic and flavonoid content compared to fresh garlic. This enhancement is attributed to release of bound phenolics and formation of low-molecular-weight antioxidant compounds during heat treatment. However, prolonged exposure may lead to degradation of thermolabile phenolics, highlighting the need for optimized processing conditions.

Color and flavor

The chemical process responsible for the transformation of garlic is mallard reaction. This occurs when reducing sugars generated during thermal degradation of fructans react with free amino groups from proteins under controlled heat conditions. As the reaction progresses, it leads to the formation of early-stage intermediates, which subsequently polymerize into melanoidins. Melanoidins are high-molecular-weight brown polymers, responsible for the characteristic dark color of black garlic. These possess significant functional properties, including antioxidant activity and metal-chelating ability.



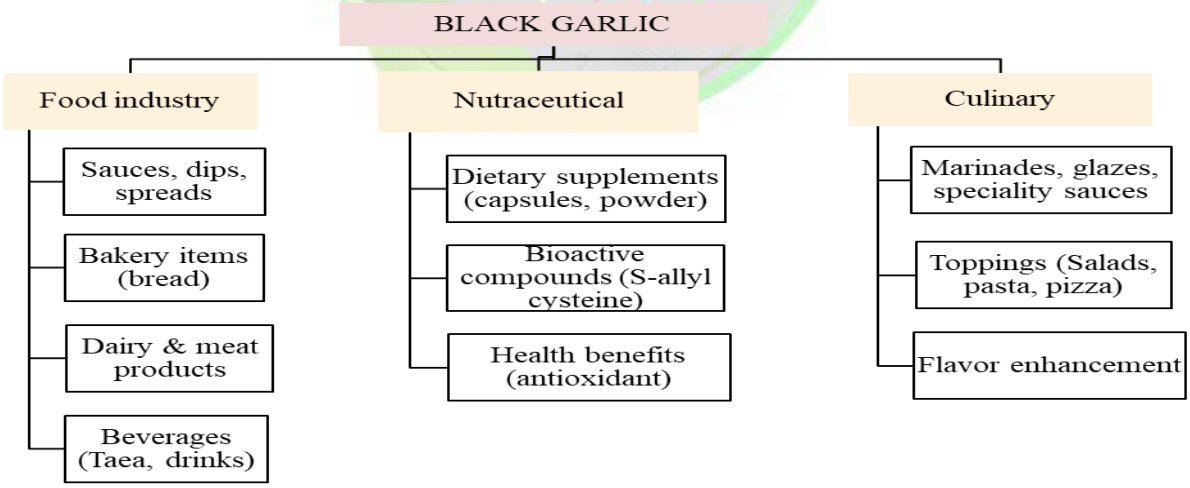
Moreover, the Maillard reaction generates a wide range of volatile compounds, including furan, thiophene, and pyrazine derivatives, which are the key contributors to the unique sweet–umami aroma of black garlic. Many of these compounds exhibit biological activities such as antioxidant, anti-inflammatory, and cytoprotective effects, further strengthening the functional value of black garlic.

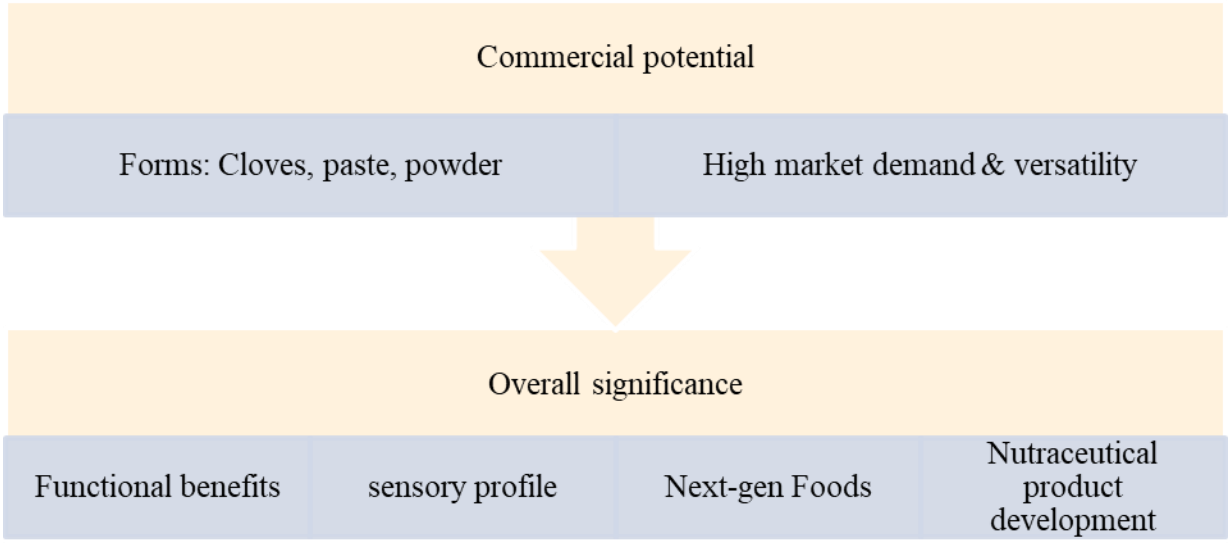
Fresh garlic vs black gralic

Fresh garlic is rich in allicin, a highly reactive organosulfur compound responsible for its strong pungency and potent antimicrobial activity. However, it is thermally unstable and undergoes rapid degradation during processing and storage. Its intense flavor and potential to cause gastrointestinal discomfort further limit its regular consumption.

In contrast, thermal processing of garlic promotes the formation of more stable organosulfur compounds, notably S-allyl cysteine (SAC) and S-allyl mercaptocysteine (SAMC). These exhibit enhanced bioavailability compared to allicin, retain strong antioxidant, cytoprotective, and anti-inflammatory activities. Thus, black garlic offers improved benefits with reduced pungency and enhanced digestibility. Functionally, black garlic demonstrates higher antioxidative potential and is better tolerated by the gastrointestinal system, making it more suitable for regular dietary intake.

Applications of Black garlic





Future Perspective

Despite the increasing interest in black garlic, several research gaps limit its full functional and commercial potential. One of the major challenges is the lack of a standardized processing protocol, as variations in temperature, humidity, and duration often lead to inconsistencies in product quality, sensory attributes, and bioactive composition. Additionally, the kinetics of bioactive compound formation and degradation during thermal aging remain insufficiently understood, making it difficult to control the accumulation of beneficial compounds such as SAC, phenolics, and melanoidins. Also, there is limited evidence regarding the bioaccessibility, bioavailability, metabolism, and in vivo effects. Addressing these gaps through comprehensive and well-designed studies will be essential to fully harness the potential of black garlic in functional food and nutraceutical applications.

Conclusion

As the demand for natural, functional foods continues to rise, black garlic stands out as a compelling example of how traditional ingredients can be reimagined through science. With further research and process optimization, it holds the potential to bridge the gap between nutrition, medicine, and modern consumer preferences.

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Volume: 06 Issue No: 10

RECOVERING PHOSPHORUS FROM AGRICULTURAL WASTES: A PATHWAY TOWARDS SUSTAINABLE AGRICULTURE IN INDIA

Article ID: AG-V06-I10-91

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Abstract

Phosphorus is an essential plant nutrient, but the increasing dependence on finite phosphate rock resources and imported fertilizers poses a major challenge to India's long-term fertilizer security. At the same time, agricultural residues, livestock manure, food-processing wastes and fishery by-products represent valuable but underutilized sources of recoverable phosphorus. Converting these wastes into useful fertilizer products offers an effective approach to reducing nutrient losses, minimizing environmental pollution and promoting a circular phosphorus economy. Technologies such as struvite precipitation, adsorption, thermochemical processing, chemical extraction, composting and biological phosphorus recovery can transform waste-derived phosphorus into agronomically valuable products, including enriched compost, biochar, calcium phosphates and slow-release fertilizers. However, their large-scale adoption depends on feedstock availability, processing costs, product quality, contaminant control and economic feasibility. Integrating remote sensing, Geographic Information Systems (GIS) and artificial intelligence can further improve waste-resource mapping, identify suitable recovery locations and support site-specific nutrient management. Strengthening research, quality standards, policy support, public–private partnerships and farmer awareness is essential to accelerate adoption.

Efficient phosphorus recovery from agricultural wastes can reduce dependence on imported mineral fertilizers while improving soil health, resource-use efficiency and environmental sustainability in Indian agriculture.

Keywords: Phosphorus recovery, agricultural wastes, circular phosphorus economy, fertilizer security.

Introduction

Phosphorus (P) is an indispensable macronutrient for plant growth, energy transfer, nucleic-acid synthesis, membrane function and food production. Yet the dominant commercial source of phosphorus fertilizers—phosphate rock—is a finite, non-renewable geological resource concentrated in a limited number of countries. India is highly dependent on imported mineral phosphorus; the source review reports a mineral P import reliance of about 93%, while the country's native high-grade rock phosphate reserves meet only a part of domestic demand. This dependence makes efficient use, recycling and recovery of phosphorus increasingly important for long-term fertilizer and food security.

At the same time, India generates enormous quantities of agricultural and agro-industrial biomass. Crop residues, livestock manure, fishery wastes, food-processing residues and other organic streams contain phosphorus that is often lost through burning, dumping, runoff or poorly managed disposal. The reviewed study therefore presents circular phosphorus management as a strategy in which waste is treated not simply as a disposal problem, but as a secondary resource from which useful phosphorus products can be recovered and returned to agriculture.

Agricultural Wastes: A Hidden Phosphorus Resource

India produces approximately 500 million tonnes of crop residues annually according to the source review. Rice straw, wheat residue and sugarcane trash form important components of the residue stream. Crop residues contain both inorganic and organic phosphorus, and their P concentration and chemical form influence how rapidly phosphorus becomes available during decomposition. The review notes that only a fraction of the phosphorus entering agriculture ultimately reaches food, highlighting the importance of recovering phosphorus at several points in the food and waste chain.

Livestock wastes are another valuable source. A large share of phosphorus consumed in animal diets is excreted, making cattle, swine and poultry manure important secondary phosphorus resources. Agro-industrial and food-processing wastes provide more concentrated

opportunities near processing centres. Fishery and aquaculture wastes, including viscera, bones and processing residues, can also provide nutrient-rich material, although rapid decomposition, dispersed generation and contamination risks require appropriate stabilization and pretreatment.

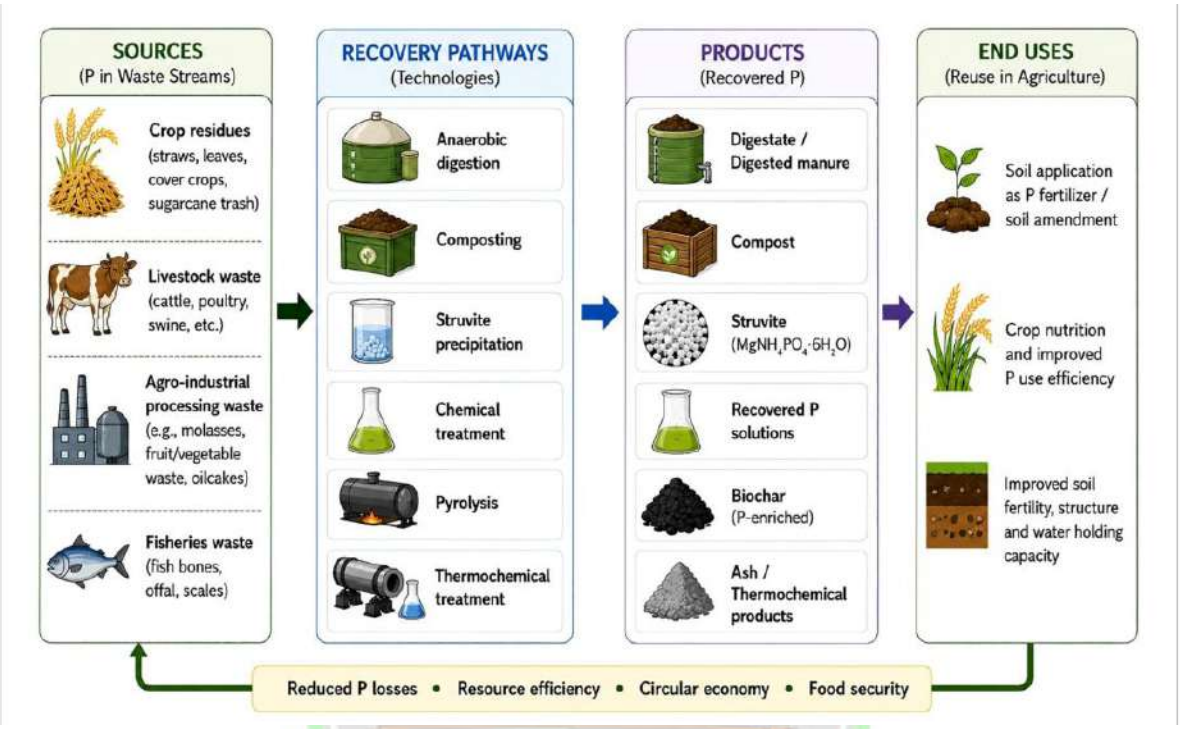


Figure 1. Phosphorus recovery from agricultural wastes: sources, recovery pathways, products and agricultural end uses

From a Linear System to a Circular Phosphorus Economy

A circular phosphorus economy aims to reduce losses at the source, recover phosphorus from waste streams and reuse the recovered nutrient in agriculture. In a conventional linear pathway, phosphorus is mined, processed into fertilizer, applied to soil, transferred through crops and animals, and finally lost through runoff, waste and disposal. A circular system interrupts this pathway by capturing phosphorus from residues, manure, digestates, processing wastes and other streams and converting it into products suitable for agricultural use.

The approach has three closely connected components. First, phosphorus losses should be reduced through balanced fertilizer use, better manure management and avoidance of residue burning. Second, phosphorus should be recovered using technologies matched to the characteristics of each feedstock. Third, recovered phosphorus should be reintegrated into soils as compost, biochar, struvite, calcium-phosphate products or other safe fertilizer formulations.

This creates a closed nutrient loop while reducing environmental leakage and dependence on virgin mineral resources.

Major Phosphorus Recovery Technologies

1. Struvite precipitation and crystallization

Struvite, MgNH4PO4·6H2O, is one of the most widely studied and commercially implemented phosphorus recovery products. It can be crystallized from manure, anaerobic digestate and wastewater when suitable concentrations of magnesium, ammonium and phosphate are present. The review reports recovery efficiencies commonly in the range of 70–90%, with higher efficiencies under optimized conditions. Struvite is particularly attractive because it provides phosphorus, nitrogen and magnesium in a slow-release fertilizer form. However, successful precipitation requires careful control of pH, magnesium dosing and the relevant molar ratios.

2. Adsorption and ion exchange

Adsorption uses solid materials to capture phosphate from liquid streams. Biochar derived from crop residues or manure can be modified with magnesium, iron or aluminium to improve phosphate capture. Such materials are especially useful for dilute phosphorus streams and can also function as soil amendments. The review emphasizes, however, that performance depends on adsorbent characteristics, surface area, pH, contact time, competing ions and regeneration requirements.

3. Thermochemical processing

Pyrolysis, hydrothermal carbonization and combustion convert biomass into stable carbonaceous products or phosphorus-rich ash. Pyrolysis can concentrate phosphorus in biochar, while hydrothermal carbonization produces nutrient-enriched hydrochar. Combustion of poultry litter can produce ash containing substantial phosphorus. These approaches reduce waste volume and can generate stable products, but energy demand, heavy-metal concentration, ash chemistry and the plant availability of phosphorus must be carefully managed.

Chemical, Biological and Hybrid Recovery

Chemical extraction and precipitation

Chemical approaches can dissolve phosphorus from manure, ash, fish waste and other materials using mineral or organic acids, followed by precipitation of a useful phosphate product. The review reports that acid leaching can recover a high proportion of solubilized phosphorus.

Calcium-phosphate minerals, including hydroxyapatite, can be produced where calcium is abundant. The main limitations are chemical consumption, possible co-extraction of heavy metals and the need to manage residual process water and solid by-products.

Biological recovery

Biological processes use microorganisms to transform phosphorus into more recoverable forms or accumulate it in biomass. Phosphate-solubilizing bacteria and fungi can release phosphorus from mineral and organic matrices through organic-acid production, proton release and phosphatase or phytase activity. Anaerobic digestion is particularly useful as a pretreatment because it can convert organic phosphorus into orthophosphate and increase ammonium availability, thereby supporting later struvite formation. Composting and vermicomposting also stabilize organic wastes while converting phosphorus into more plant-available forms.

Hybrid systems: combining strengths

No single recovery technology is ideal for every waste stream. Hybrid systems therefore combine complementary operations. Examples discussed in the source include digestion followed by struvite crystallization and adsorption, or thermochemical treatment followed by acid extraction. Such combinations can address different phosphorus fractions and may achieve high overall recovery. The trade-off is greater process complexity, energy use, chemical consumption and monitoring requirements.

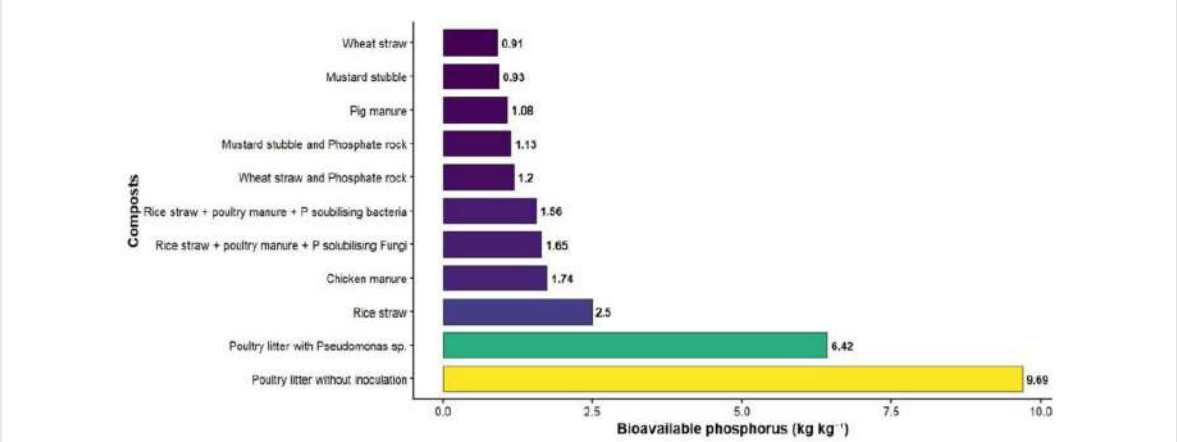


FIGURE 2
Bioavailable P values in different types of compost (Billah and Bano, 2015; Moharana et al., 2020; Gaind, 2014; Moharana et al., 2020; Wei et al., 2015).

Figure 2. Bioavailable phosphorus values reported for different compost types in the reviewed studies.

Recovered Products and Agricultural Value

The objective of phosphorus recovery is not merely removal from waste; it is production of safe, agronomically useful materials. Enriched composts can supply phosphorus while improving soil organic matter and biological activity. The review reports that composting and vermicomposting can retain nearly all of the original phosphorus and may substantially increase the proportion present in plant-available forms. Phosphorus-loaded biochar can combine nutrient delivery with carbon storage, water retention and improved soil biological properties.

Slow- and Controlled-Release Fertilizers

Struvite, hydroxyapatite, calcium phosphates and phosphorus-loaded biochars can be developed as slow- or controlled-release fertilizers. Their gradual phosphorus release can reduce leaching and provide a more sustained nutrient supply. The source review reports that struvite supplies phosphorus together with nitrogen and magnesium and has shown useful performance in crop studies. Polymer, clay and biochar matrices can further regulate nutrient diffusion. Such technologies are especially promising where rapid nutrient loss is a concern, although performance depends strongly on soil properties and formulation.

Challenges to Large-Scale Adoption in India

The major barriers are not technological alone. Agricultural wastes are spatially dispersed, seasonal and highly variable in moisture content and phosphorus form. Collection, segregation, transport and storage can therefore become costly. Centralized plants may struggle to obtain a consistent feedstock, whereas decentralized systems require appropriate local technology and management. The quality and safety of recovered products are also critical because livestock, aquaculture and agro-industrial wastes may contain pathogens, antibiotics, pesticide residues, heavy metals or other contaminants.

Economic viability is another major concern. Advanced recovery facilities may require reactors, pH-control systems, chemical inputs, membrane units or high-temperature equipment. Small and marginal farmers may not be able to invest in such infrastructure individually. The review consequently emphasizes techno-economic evaluation, modular systems, public-private partnerships, improved logistics and market development for recovered fertilizers.

Policy, Digital Technologies and the Way Forward

A successful circular phosphorus economy requires quality standards, certification, clear product labelling, incentives and farmer-oriented demonstrations. The source review highlights

Indian initiatives such as PM-PRANAM, GOBAR-DHAN and the Crop Residue Management Scheme as relevant policy platforms, while stressing that waste management must be linked to a market for safe and standardized recovered nutrient products.

An important future direction is the integration of Remote Sensing, GIS, artificial intelligence and machine learning with waste-resource management. Remote sensing can identify residue distribution and burning hotspots; GIS can combine crop intensity, livestock density, transport networks, soil phosphorus status and waste generation to locate suitable recovery centres; and machine-learning models can help predict recovery performance under different feedstocks and processing conditions. These tools can support decentralized, location-specific circular nutrient management.

Conclusion

Phosphorus recovery from agricultural wastes offers India an opportunity to transform a nutrient-loss and waste-disposal problem into a resource-security strategy. Crop residues, livestock manure, agro-industrial wastes and fishery by-products contain recoverable phosphorus that can be converted into composts, biochars, struvite, calcium-phosphate materials and advanced slow-release fertilizers. The most suitable technology must be selected according to feedstock composition, local availability, collection feasibility, energy requirements and end-use objectives.

Closing the phosphorus loop will require more than new technology. It will require coordinated action by farmers, researchers, industries, policymakers and local institutions; investment in collection and processing infrastructure; reliable product standards; farmer education; and economically viable markets. With these elements in place, circular phosphorus management can contribute simultaneously to fertilizer security, soil health, waste reduction and environmental sustainability in India.

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Volume: 06 Issue No: 10

STICKY ALLIES IN THE SOIL: HOW BACTERIAL EXOPOLYSACCHARIDES EASE SALT STRESS IN CROPS

Article ID: AG-VO6-I10-92

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Abstract

Salt-affected soils reduce crop yields on millions of hectares in India. Removing the salt needs drainage, water and soil amendments, but beneficial soil bacteria can help crops cope in the meantime. Many root-associated bacteria release exopolysaccharides, sticky sugar-based polymers that form a gel-like sheath around roots and bind soil particles into stable aggregates. This sheath can restrict the entry of sodium into roots, hold moisture near them, and improve soil structure so that water and salts move downward more easily. Pot experiments with wheat have shown large gains in root and shoot growth after inoculation, although field evidence is less consistent. This article explains how these polymers work, what they cannot do, and how they fit into an integrated salinity management plan.

Key words: Exopolysaccharides, Soil salinity, Sodium exclusion, Soil aggregation, Wheat

Introduction

A white crust on a dry field, stunted seedlings and patches where nothing grows: this is the face of soil salinity. In India about 6.73 million hectares are salt-affected, and the area could reach 16.2 million hectares by 2050 if present trends continue.[1] Research institutes have already reclaimed about 2.2 million hectares through drainage, gypsum and salt-tolerant varieties.[2] These methods remain the backbone of reclamation, but they are costly and slow. Scientists are therefore asking a quieter question: can the microbes living around roots make crops more resilient to salt? One of the most promising answers lies in a sticky substance that many soil bacteria make, called exopolysaccharide (EPS).

What are exopolysaccharides?

Exopolysaccharides are long, sugar-based chains that bacteria secrete outside their cells. Think of them as the slime on a river stone. Soil bacteria such as *Bacillus*, *Pseudomonas*, *Rhizobium* and *Pantoea* produce them to stay moist, to stick to roots and to protect themselves from stress.[3,4] Because the chains carry electrical charges, they can attract and hold positively charged ions such as sodium, and because they swell with water, they hold moisture like a sponge.[5]

How the sticky shield works

Sheath around the root. (Figure 1) In a pot study in saline soil, five exopolysaccharide-producing bacterial strains were added to wheat seedlings. Root dry matter rose by 149 to 527 per cent and shoot dry matter by 85 to 281 per cent compared with plants without the bacteria (Figure 3). Sodium entry into the roots dropped. The authors suggested the likely reason was physical: a thicker sheath of soil and bacterial slime covering more of the root surface reduced the passive flow of sodium into the root core.[6]

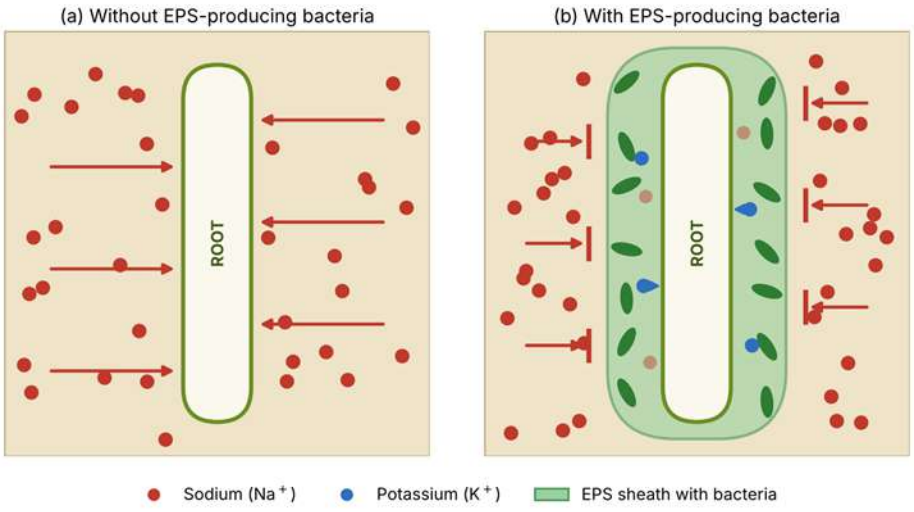


Figure 1. Sodium (red) streams towards an unprotected root (a), but a sheath of bacteria and exopolysaccharide (green) slows its entry while potassium (blue) is retained (b). Schematic, not to scale.

Sodium binding. Reviews also report that exopolysaccharides can bind sodium ions in the soil solution, leaving less available for the plant to absorb.[5] In the wheat study above, binding by the root-zone soil did not explain the lower sodium uptake, so the sheath effect and chemical binding probably act together to different degrees depending on the strain and soil.[6]

Better soil structure. Salty, sodium-rich soils tend to fall apart into fine particles that seal the surface, so water stands and cannot wash salts downward. Exopolysaccharide-producing bacteria glue particles into small crumbs called aggregates, as shown for sunflower, wheat and in soil from arid regions.[3,4,7] The gaps between crumbs let water enter and move, which makes leaching of salts more effective (Figure 2). The same aggregates also protect organic matter, so a healthier structure supports soil carbon too.

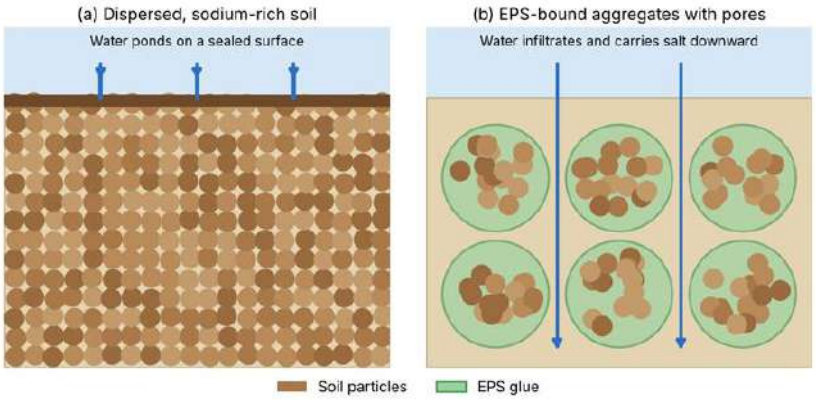


Figure 2. Dispersed soil seals and floods (a); exopolysaccharide-bound aggregates open pathways for water and salts (b). Schematic.

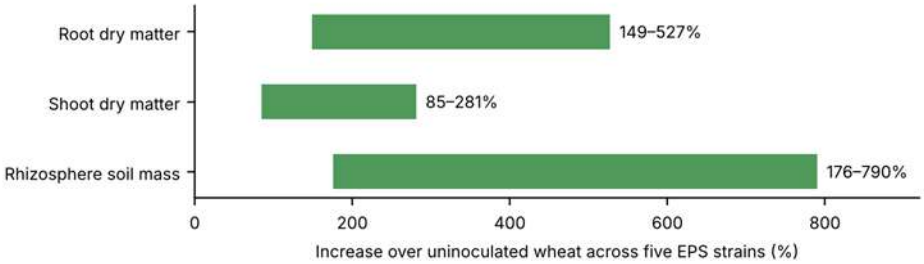


Figure 3. Gain in wheat growth in saline soil after inoculation with five exopolysaccharide-producing bacterial strains (range across strains), pot experiment.[6]

What it cannot do

It is important to be honest about limits. Exopolysaccharides do not remove salt from the soil: sodium is held back or flushed deeper, but it is still there. Most of the encouraging numbers come from pots and greenhouses, where conditions are controlled. In real fields, introduced bacteria must compete with native microbes, and results vary with strain, crop, soil and salt level.[2] Bacterial products should therefore be treated as a helper to, never a replacement for, drainage, good-quality water, gypsum on sodic soils and salt-tolerant varieties.

Practical pointers for farmers

Choose products or strains that were tested on your crop and in similar salty soils.

Start on a small plot beside an untreated strip to see the difference with your own eyes. Add organic manure or crop residues, which feed beneficial microbes. Keep drainage and leaching going. Consult the nearest Krishi Vigyan Kendra or agricultural university before buying a bio-inoculant.

Conclusion

Bacterial exopolysaccharides act as a living, self-renewing glue and sponge around plant roots. By cushioning crops against sodium, retaining moisture and rebuilding soil crumbs, they can help plants survive salty conditions and may support carbon storage as well. The science is promising but still maturing, and the most realistic role for these microbes is as a partner to proven reclamation practices rather than a stand-alone cure.

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Volume: 06 Issue No: 10

AGRIPRENEURSHIP AS CHANGE AGENTS FOR AGRICULTURAL TRANSFORMATIONS- A KERALA PERSPECTIVE

Article ID: AG-VO6-I10-93

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Abstract

The Indian economy is dependent on the agriculture to great extent. More than fifty percent of the population in the country is dependent on agriculture for their livelihood. The farmers in India are facing different types of glitches. The major problem faced by them is regarding the marketing of the product. They are producing in the large quantities but they are not able to get the required rate for their produce. Promotion of entrepreneurial skills among them will help them to increase their sale as well as the amount of profits. Agripreneur is an entrepreneur whose base of business is agriculture or agriculture related. They are adopting innovative ideas in agriculture to market their products more efficiently. Agripreneurship is an entrepreneurial process in agriculture for getting better output and better profitability. With regard to the present situation prevailing in the economy there is a lot of opportunities available for the agripreneurs to capture the market and increase their earnings. At the same time there will be hurdles in achieving this objective. This study aims to study the potential areas and opportunities for Agripreneurship in India and to identify the various forms of Agripreneurship. Further it also identifies various problems or challenges and future strategies for promoting Agripreneurship in India and how it can have an agriculture transformation; which can be broadly defined as the process over time by which the agri-food system transforms from subsistence oriented and farm centred into more commercialised, productive and off-farm centred.

Keywords: Agripreneurship, agripreneur, Agricultural transformation,

Introduction

Agricultural transformation is the process that leads to increased farm productivity,

making farming commercially viable and strengthening interlinkages with other sectors of the economy. For agricultural transformation, there are key areas that require focus. Farmer's access to financial resources and mechanisation of agriculture is the major challenges that India faces. Even though there has been an increase in the sales of tractors all across India giving rise to mechanization in the sector, it is also important to make mechanized equipment accessible to all farmers, including the farmers with small and scattered land holdings.

Mechanization of the agriculture sector is imperative to increase the productivity of the farmers but it should also occur in an environmentally-sustainable manner. Mechanization in the agricultural sector consists of using machinery, tools and equipment to reduce post-harvest losses, get good quality products and increase the value of the farm product. It helps in increasing the economic benefits for the farmers who can efficiently use their manpower, reduce input costs and increase the value of output, adopt diversification of crops and in turn, improve their welfare. The focus of mechanization in agriculture is to augment the farmer by increasing their per hectare productivity and replacing the efforts of animal or manual labour with mechanical power. Mechanization can take place in two ways; 'partially' when machines only replace a part of the farming activity or 'completely' when machinery replaces animals and human labour entirely. In India, there are inter-regional differences in the level of mechanization. The Northern-Indian states like Uttar Pradesh, Punjab and Haryana experience a high level of mechanization due to the presence of highly fertile lands and state-specific policies. In the southern and eastern states of India, the level of mechanization is low due to the hilly topography and high cost of transportation.

From the point of agricultural development, Mellor divides agriculture into three stages.

The stages are: 1. Traditional Agriculture 2. Technologically Dynamics Agriculture-Low Capital Technology 3. Technologically Dynamic Agriculture High Capital Technology.

Stage # 1. Traditional Agriculture:

"It is a technologically stagnant stage in which production is increased largely through slowly increased application of traditional forms of land, labour and capital." The increase in output takes place through an essentially symmetrical expansion of all inputs or through increased input of the already abundant low productivity resources. Declining income and productivity per unit of an input is a common feature of this phase.

Stage # 2. Technologically Dynamics Agriculture-Low Capital Technology:

In stage II, **"**a complex of technological changes substantially increases the efficiency of agricultural processes and raises the rate of increase of agricultural production……. The critical characteristics of stage II, as compared with stage I is the constant generation and application of technology which is facilitated by a complex institutional framework…"

In this stage:

(a) Agriculture still represents a large proportion of the total economy

(b) Demand for agricultural products is rising rapidly due to both demographic and income effects,

(c) Capital for industrial development is particularly scarce and returns are rising

(d) Limitations to the pace of economic transformation and pressure of population growth preclude enlargement of the average acreage per farm and

(e) Use of labour saving agricultural machinery is largely precluded by unfavourable labour-capital cost relationships. These conditions call for a type of agricultural development which at one time not possible, but which is now facilitated by modern science.

Stage # 3. Technologically Dynamic Agriculture High Capital Technology:

This is the stage when agriculture has much of its relative importance in the generation of the National Income. Agriculture of various developed countries is included in this stage. Government's role in different stages is quite important. In nature, of course, it is different. We would like to highlight the objectives and important policy measures relevant for each stage in the paragraphs that follow. It may be noted that as the stage of agricultural development cannot be very finely demarcated, the objectives of agricultural policy at a particular time, too cannot be defined rigidly. What we find at a particular point of time is a set of objectives, their order of priority, of course, changing as the time changes. We shall be giving below only the relatively more important policy objectives vis-a vis agriculture in different stages of development.

AGRIPRENEURSHIP AS CHANGE AGENTS FOR AGRICULTURAL TRANSFORMATION IN KERALA: The Enabler and Traceability Model

1. Introduction: Redefining the Agripreneur for Kerala

The conventional understanding of an agripreneur as a person who does farming as a business is flawed for Kerala. With 99.5% of farmers being small and marginal with an average holding of

0.18 Ha, Kerala does not need more individuals entering farming to become big landowners. It needs agribusinesses that exist FOR agriculture, not the other way around.

The real crisis in Kerala is not production - our homesteads still produce. The crisis is marketing. A farmer in Idukki gets Rs. 18/kg for passion fruit that sells for Rs. 180/kg in a Kochi supermarket. The gap is not yield, it is value chain.

Therefore, the true change agent is the Enabler-Agripreneur - one who does not compete with the farmer for land, but provides him with the three things he lacks: Market Access, Value Addition, and Transparency.

2. The Core Problem: Why Small Farmers Remain Poor in a Rich Market

Kerala has the highest consumer spend on food, yet the lowest farmer profitability. Why?

Disorganised Supply Chain: 5-7 middlemen between farmer and consumer. No Identity: The consumer eats Wayanad pepper but never knows which farmer grew it. The farmer remains invisible. No Accountability: When produce is mixed at the wholesale market, there is no incentive for quality, organic practices, or fair price. The result: The farmer is a price-taker, not a price-maker.

3. The Enabler Model: Agribusiness FOR Agriculture

We propose a paradigm shift from Farm-to-Business to Business-to-Farm Service Model. Old Model (Flawed)New Enabler Model (Proposed for Kerala) Agripreneur buys/leases land and farms Agripreneur does NOT buy land, but aggregates from 500 existing small farmers Profit stays with the agripreneur Profit is shared; agripreneur earns a service fee/margin Farmer becomes labourer Farmer remains owner-entrepreneur Business OF agriculture Business FOR agriculture Three Roles of the Enabler:

A. As Marketing Agent: The agripreneur becomes the dedicated marketing arm of an FPO. He handles branding, e-commerce (ONDC, Lulu, Nesto), export compliance - things a small farmer can never do alone.

B. As Value-Addition Agent: Instead of one farmer trying to make virgin coconut oil, the agripreneur sets up a common processing centre that processes coconut from 300 homesteads under one brand.

C. As Service Agent: Custom Hiring Centres, drone spraying services, soil testing vans - where farmers pay per use, without owning the machinery.

Live Example: Sanjeevani FPO in Thrissur - An agripreneur runs the packhouse, but the farm remains with 400 tribal women. Their income doubled, not because they grew more, but because their produce finally reached the market.

4. The Game Changer: Traceability and Accountability as Transformation

This is where Kerala can lead India. Our consumers are literate and willing to pay for authenticity. The missing link is transparency.

We propose the "Farmer Tag" system - Every pack consumed by the end user carries a tagline and a QR code that tells the farmer's story.

From Anonymous Commodity to Accountable Identity. How it works:

QR Code on Every Pack: A simple QR code printed on banana chips, pepper powder, or honey bottle. Scan to Experience the Farmer: When a consumer in Dubai or Ernakulam scans it, he sees: Farmer's Name (e.g., Rajan, Wayanad), Photo of his farm, Date of Harvest, Organic Certificate, and the price he received. What it creates: For Consumer: Trust, Emotional Connect, Willingness to pay 30% premium. He is not just buying a product, he is experiencing a farmer. For Farmer: Accountability, Pride, and Power. His name is on the product. He cannot cheat, and the market cannot cheat him. For System: Organised Platform. Data of who grew what, where, and when is now documented. This creates a formal, organised, bankable agricultural database - transforming Kerala's unorganised homestead farming into an organised sector. Technology: This is low-cost and ready. Blockchain-based traceability platforms like TraceX, AgriTrust or even a simple Google Sheets linked QR via KAU's ABI can do this. VFPCK has already piloted this for pineapples.

Tagline Example on Pack:

"This pepper was grown by Leela Chechi, Meenangadi, Wayanad. Harvested on 12th May 2026. She received Rs. 145/kg - Fair Price Guaranteed. - Scan to meet your farmer. "This single line does what 50 years of subsidies could not - it restores dignity.

5. A Refined Transformation to an Organised Platform

When traceability is combined with the enabler model, Kerala agriculture transforms:

Unorganised -> Organised: 1,000 scattered farmers become one digital co-operative with traceable output.

Commodity -> Brand: "Kerala Pepper" becomes "Wayanad Pepper by Rajan's Collective - GI Tagged, Farmer Traced".

Distress Sale -> Demand-Driven: End user data shows what sells. Agripreneur tells FPO what to grow next season.

This is how Israel and Netherlands did it - not by having big farms, but by having highly organised small farmers connected to global markets through strong enabler institutions.

Conclusion

Agripreneurship in Kerala must not be measured by how much land an agripreneur owns, but by how many small farmers he liberated from the middleman. The true transformation will not happen when we have 100 smart farms, but when we have 100 smart enablers who make 10,000 existing small farms profitable. The future is not Farming for Business, but Business for the Farmer - a business that guarantees that the farmer is seen, paid, and respected. By embedding traceability and accountability into every pack, we are doing more than selling a product. We are selling transparency. We are ensuring that when a child in Kochi opens a pack of banana chips, he doesn't just taste a snack; he experiences the farmer, his land, and his labour. This emotional and digital connection is what will finally organize Kerala's agriculture and make it immortal. The best agripreneur does not put his own brand on the farmer's produce. He puts the farmer's name on his brand.

Volume: 06 Issue No: 10

NATURAL RESOURCE MANAGEMENT AND LIVELIHOOD SUSTAINABILITY IN RAINFED REGIONS

Article ID: AG-VO6-I10-94

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Abstract

Rainfed regions support a large proportion of smallholder farmers and contribute significantly to food security, employment, and rural livelihoods, yet they remain highly vulnerable to rainfall variability, drought, soil degradation, and climate change. Sustainable management of natural resources is therefore essential for improving productivity and ensuring long-term livelihood security in these areas. This article examines the role of Natural Resource Management (NRM) in enhancing livelihood sustainability in rainfed ecosystems. It discusses major resource-related challenges, including soil erosion, declining soil fertility, water scarcity, vegetation degradation, and biodiversity loss. The article highlights integrated watershed management, soil and moisture conservation, integrated nutrient management, agroforestry, and sustainable livestock management as key strategies for improving resource-use efficiency and ecological resilience. It further explores the linkages between NRM and livelihood outcomes such as increased agricultural productivity, income diversification, employment generation, food and nutritional security, and reduced vulnerability to climatic shocks. The importance of community participation, local institutions, and convergence of government programs is emphasized for achieving long-term sustainability. Emerging opportunities through digital agriculture, climate advisories, remote sensing, and ecosystem-based approaches are also discussed. The article concludes that integrated, participatory, and climate-resilient NRM interventions are fundamental for restoring degraded rainfed landscapes, strengthening rural livelihoods, and promoting sustainable agricultural development in vulnerable regions.

Keywords: Natural Resource Management, Rainfed Agriculture, Livelihood Sustainability, Watershed Management, Soil and Water Conservation, Agroforestry, Climate Resilience.

Introduction

Rainfed regions constitute one of the most important components of the agricultural economy in developing countries, particularly in India, where a substantial proportion of cultivated land depends entirely on rainfall for crop production. Unlike irrigated systems, rainfed agriculture relies on the quantity, distribution, intensity, and timing of seasonal rainfall, making it highly vulnerable to climatic variability. These regions are predominantly located in arid, semi-arid, and sub-humid agro-ecological zones and are characterized by erratic precipitation, frequent dry spells, recurrent droughts, soil erosion, declining soil fertility, and inadequate irrigation infrastructure. As a result, agricultural production in rainfed areas is often unstable and associated with high levels of risk and uncertainty for farming households.

Despite these limitations, rainfed agriculture remains the backbone of rural livelihoods for millions of small and marginal farmers. In India, rainfed areas account for nearly two-thirds of the net sown area and contribute significantly to the production of pulses, oilseeds, coarse cereals, fodder crops, and livestock products. These regions support a large share of the rural population and provide employment opportunities not only through crop cultivation but also through livestock rearing, collection of forest products, agro-processing, and other allied activities. Therefore, the socio-economic well-being of rural communities in rainfed areas is intimately connected with the health and productivity of the natural resource base.

The sustainability of livelihoods in rainfed ecosystems depends largely on the availability and management of critical natural resources, including soil, water, vegetation, forests, grazing lands, and biodiversity. Soil serves as the primary medium for crop growth, while water availability determines agricultural productivity and household security. Vegetation and biodiversity provide essential ecosystem services such as nutrient cycling, carbon sequestration, pollination, fodder supply, fuelwood, and climate regulation. However, increasing population pressure, expansion of cultivation into marginal lands, overgrazing, deforestation, unsustainable farming practices, and climate change have accelerated the degradation of these resources. Soil organic matter depletion, groundwater decline, loss of vegetative cover, and reduced biodiversity have emerged as major constraints to sustainable agricultural development in rainfed regions.

Climate change has further intensified these challenges by increasing the frequency and severity of extreme weather events, including prolonged droughts, heat waves, and intense rainfall episodes. Such events adversely affect crop yields, livestock productivity, water availability, and household incomes, thereby increasing the vulnerability of resource-poor farmers. In this context, enhancing the resilience of rainfed farming systems has become a national and global priority for achieving food security, poverty reduction, and sustainable development.

Natural Resource Management (NRM) has emerged as a comprehensive approach for addressing these interconnected challenges. NRM involves the planned conservation, restoration, utilization, and governance of land, water, forests, and biodiversity in a manner that balances productivity, environmental sustainability, and social equity. In rainfed regions, effective NRM practices such as watershed management, soil and moisture conservation, rainwater harvesting, integrated nutrient management, agroforestry, pasture development, and community-based resource governance can significantly improve resource-use efficiency and ecosystem health. These interventions help reduce runoff and soil erosion, enhance groundwater recharge, improve soil fertility, increase biomass production, and stabilize agricultural yields.

Importantly, NRM extends beyond environmental conservation and has direct implications for livelihood sustainability. By improving the productivity and reliability of natural resources, NRM enhances farm income, diversifies livelihood opportunities, generates rural employment, strengthens food and nutritional security, and reduces vulnerability to climatic and economic shocks. Community participation and local institutional involvement are also critical for ensuring equitable access to resources and the long-term maintenance of conservation measures.

Given the increasing pressures on land and water resources and the growing impacts of climate change, there is an urgent need to promote integrated and participatory NRM strategies in rainfed regions. Understanding the linkages between natural resource management and livelihood sustainability is essential for designing policies, technologies, and development programs that can restore degraded ecosystems while improving the socio-economic conditions of rural communities. This article therefore examines the importance of NRM in rainfed areas, the major resource-related challenges, the key management strategies, and their role in achieving sustainable livelihoods and resilient agricultural systems.

Importance of Rainfed Regions

Rainfed areas account for nearly 60–65% of the cultivated land in India and support a majority of small and marginal farmers. These regions are often located in arid, semi-arid, and sub-humid agro-ecological zones where rainfall is unevenly distributed both spatially and temporally. Agriculture in such areas is highly vulnerable to climate variability, making farmers dependent on local natural resources for crop production, livestock rearing, fuelwood, fodder, and household needs. Consequently, degradation of these resources directly affects income, nutrition, and social well-being.

Concept of Natural Resource Management

Natural Resource Management refers to the planned utilization, conservation, restoration, and sustainable management of land, water, forests, biodiversity, and other natural assets to meet present needs without compromising the ability of future generations to meet their own needs. In rainfed regions, NRM aims to:

- Improve soil health and fertility.
- Enhance water availability and use efficiency.
- Reduce land degradation and erosion.
- Conserve biodiversity and ecosystem services.
- Strengthen livelihood resilience against climatic shocks.

An integrated and participatory approach is essential because soil, water, vegetation, livestock, and human activities are interdependent components of the rainfed ecosystem.

Major Natural Resource Challenges in Rainfed Areas

Soil Degradation: Continuous cultivation, inadequate nutrient replenishment, excessive tillage, and removal of crop residues lead to loss of organic matter, nutrient depletion, soil erosion, and reduced water-holding capacity. Declining soil health lowers crop productivity and increases vulnerability to drought.

Water Scarcity: Rainfall in rainfed regions is often intense but short-lived, resulting in high runoff and low groundwater recharge. Limited water storage structures and poor watershed management exacerbate water scarcity during dry spells.

Vegetation Loss and Biodiversity Decline: Deforestation, overgrazing, and expansion of cultivated land reduce vegetation cover, disturb ecological balance, and diminish the availability of fodder, fuel, and non-timber forest products.

Climate Variability: Increasing frequency of droughts, delayed monsoons, heat waves, and extreme rainfall events adversely affect crop yields, livestock health, and household incomes.

Strategies for Sustainable Natural Resource Management

Watershed Management: Watershed management is one of the most effective approaches for rainfed regions. It involves treating the entire drainage area through soil and water conservation measures such as contour bunding, graded bunds, check dams, farm ponds, percolation tanks, vegetative barriers, and gully plugging. These interventions reduce runoff, increase infiltration, recharge groundwater, and improve moisture availability for crops.

Successful watershed programs have demonstrated improvements in agricultural productivity, drinking water availability, fodder production, and rural employment.

Soil and Moisture Conservation: Conservation practices help retain soil fertility and moisture. Important measures include:

- Contour farming
- Mulching
- Conservation tillage
- Cover cropping
- Crop residue retention
- Terracing on sloping lands

These practices reduce erosion, moderate soil temperature, enhance microbial activity, and improve water-use efficiency.

Integrated Nutrient Management: Sustainable soil fertility requires a balanced use of organic and inorganic nutrient sources. Farmyard manure, compost, green manure, crop residues, biofertilizers, vermicompost, Jeevamrut, and Panchagavya can improve soil organic carbon, nutrient availability, and biological activity. Integrated nutrient management not only increases yields but also reduces dependence on costly chemical fertilizers.

Agroforestry Systems: Agroforestry integrates trees with crops and/or livestock, providing multiple ecological and economic benefits. Trees improve soil structure, reduce wind erosion, enhance carbon sequestration, and provide fuelwood, fodder, fruits, timber, and additional income. In rainfed regions, agroforestry acts as a buffer against crop failure and diversifies livelihood sources.

Sustainable Grazing and Livestock Management: Livestock are integral to rainfed livelihoods. Controlled grazing, pasture development, fodder banks, silvi-pastoral systems, and improved animal health services help maintain rangeland productivity and enhance livestock-based income.

Linkages Between NRM and Livelihood Sustainability

Livelihood sustainability refers to the ability of households to maintain and improve their living standards while coping with shocks and stresses. Effective NRM contributes to livelihood sustainability through several pathways.

Enhanced Agricultural Productivity: Improved soil moisture, fertility, and water availability lead to higher and more stable crop yields, reducing the risk of crop failure.

Income Diversification: Agroforestry, horticulture, livestock, fisheries in farm ponds, and value addition of natural products create multiple income streams, reducing dependence on a single crop.

Employment Generation: Construction and maintenance of watershed structures, plantation activities, and community resource management generate local employment, particularly during lean agricultural periods.

Reduced Vulnerability: Healthy ecosystems provide resilience against droughts, floods, and climate extremes. Households with diversified resource-based livelihoods are better able to withstand economic and environmental shocks.

Improved Food and Nutritional Security: Increased production of cereals, pulses, oilseeds, fruits, vegetables, milk, and meat enhances dietary diversity and nutritional outcomes.

Role of Community Participation

Sustainable NRM cannot be achieved through top-down interventions alone. Community participation is essential for planning, implementation, maintenance, and equitable sharing of benefits. Village institutions, self-help groups, water user associations, and watershed committees play important roles in:

- Resource mapping
- Decision-making
- Conflict resolution
- Monitoring resource use
- Ensuring long-term maintenance of assets

Participatory approaches foster ownership, accountability, and social cohesion, which are critical for the success of NRM programs.

Policy and Institutional Support

Government initiatives such as the Integrated Watershed Management Programme (IWMP), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), National Mission for Sustainable Agriculture (NMSA), and various state-level watershed programs have promoted NRM in rainfed areas. Convergence of these schemes can enhance resource efficiency, avoid duplication, and create durable livelihood assets.

Research institutions, agricultural universities, Krishi Vigyan Kendras, and extension agencies also play a vital role in developing location-specific technologies and building farmers' capacities.

Emerging Opportunities

Recent advances offer new opportunities for strengthening NRM in rainfed regions:

- Remote sensing and GIS for watershed planning
- Weather forecasting and climate advisories
- Drought-tolerant crop varieties
- Precision nutrient and water management
- Digital agriculture and mobile-based extension
- Carbon farming and ecosystem service payments

Integrating traditional knowledge with modern science can further enhance the effectiveness of resource management strategies.

Conclusion

Natural Resource Management is the foundation of livelihood sustainability in rainfed regions. Soil, water, vegetation, and biodiversity are not merely environmental assets but the primary means of survival for millions of rural households. Integrated watershed management, soil and moisture conservation, agroforestry, sustainable livestock management, and community participation can significantly improve resource productivity, resilience, and income security. In the context of climate change and increasing resource pressure, strengthening NRM through participatory, science-based, and policy-supported approaches is essential for achieving

sustainable agriculture, rural development, and long-term livelihood security in rainfed ecosystems.

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Volume: 06 Issue No: 10

EPIGENETIC REGULATION OF DISEASE RESISTANCE IN FISH

Article ID: AG-VO6-I10-95

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Abstract

Disease outbreaks remain a major challenge in aquaculture, affecting fish welfare, farm productivity and profitability. Fish defence is shaped not only by inherited DNA sequence but also by epigenetic regulation—the molecular processes that influence when and how genes are switched on or off. Major mechanisms include DNA methylation, histone modifications and non-coding RNAs such as microRNAs. These mechanisms can alter the expression of immune-related genes involved in pathogen recognition, inflammation, antimicrobial activity and immune-cell function. Nutrition, temperature, water quality, stress and previous exposure to microbes may also influence epigenetic patterns. This creates opportunities to investigate immune priming, broodstock management and improved disease-resilience strategies. However, epigenetic changes do not automatically produce protection, and evidence for stable inheritance across multiple fish generations remains limited. This article explains the main mechanisms in accessible language, discusses possible applications in aquaculture and highlights the research needed before epigenetic tools can be routinely used in fish-health management.

Keywords: Epigenetics, fish health, disease resistance, DNA methylation, histone modification, microRNA, aquaculture

Introduction

Aquaculture is an important source of food and livelihoods, but infectious diseases caused by bacteria, viruses, fungi and parasites can reduce survival and increase production costs. Fish-health management commonly relies on good water quality, biosecurity, vaccination where available, nutrition, selective breeding and responsible treatment. An emerging question is whether the way fish use their genes can also help explain why some individuals cope with infection better than others.

The DNA sequence is like a set of instructions, while epigenetic regulation is one way the cell decides which instructions to read, when to read them and how strongly to use them. Epigenetic mechanisms generally do not change the underlying DNA letters. Instead, they influence the packaging of DNA or the availability and stability of genetic messages. The same genome can therefore support different patterns of gene activity in different tissues, developmental stages or environments (Anastasiadi et al., 2018; Liu et al., 2022).

For fish, this field is promising because aquatic animals experience changing temperatures, oxygen levels, diets, stocking densities and microbial environments. These factors may interact with epigenetic processes and immune function. The goal is not to replace established disease prevention, but to understand whether epigenetic knowledge can complement breeding and health-management programmes.

What does epigenetic regulation mean?

Epigenetics refers to changes in gene activity that occur without changing the DNA sequence itself. Some epigenetic marks are reversible, and their effects depend on the gene, tissue, developmental stage and environmental context. Three widely studied mechanisms are DNA methylation, histone modification and non-coding RNA regulation.

1 DNA methylation: A molecular dimmer switch

DNA methylation involves adding a small chemical group, commonly to cytosine bases in DNA. When methylation occurs in certain regulatory regions, especially some gene promoters, it can reduce gene transcription. The effect is not universal: the outcome depends on where methylation occurs and the surrounding regulatory context. In immune-related genes, changes in methylation may therefore be associated with altered readiness or intensity of a response to infection (Liu et al., 2022).

2 Histone modifications: Opening or tightening the DNA package

DNA is wrapped around proteins called histones. Chemical changes to histones—including acetylation and methylation—can alter how accessible a region of DNA is to the machinery that reads genes. Some histone marks are associated with active transcription, while others are associated with repression. The combined pattern of marks, rather than one mark alone, helps determine gene activity. In fish, the contribution of specific histone marks to disease resistance is an active research area.

3 Non-coding RNAs: Fine-tuning the message

Not every RNA molecule is used to make a protein. MicroRNAs (miRNAs) are small non-coding RNAs that can bind to target messenger RNAs and reduce their translation or promote their breakdown. By adjusting the abundance of particular messages, miRNAs may help balance immune activation and inflammation. This balance matters because an insufficient response may allow a pathogen to spread, whereas an excessive response can damage the fish's own tissues.

Figure 1. Conceptual pathway linking environment, epigenetics and fish disease resistance

ENVIRONMENT & MANAGEMENT

Nutrition • Temperature • Water quality • Stress • Microbial exposure

↓

EPIGENETIC REGULATION

DNA methylation • Histone modifications • Non-coding RNAs

↓

CHANGES IN GENE EXPRESSION

Pathogen recognition • Cytokines • Antimicrobial responses • Inflammation control

↓

POSSIBLE OUTCOME

Altered immune readiness and disease resilience (depends on species and context)

.How can epigenetics influence fish disease resistance?

The immune system must recognise harmful microbes, coordinate cellular and chemical defences, and then control inflammation so that tissues can recover. Epigenetic regulation may influence several parts of this process. For example, changes in gene accessibility can affect the expression of receptors involved in pathogen recognition, signalling molecules that coordinate

immune cells, and proteins that contribute to antimicrobial defence. Non-coding RNAs may further tune the duration and intensity of these responses.

Fish disease resistance is a complex trait. It is influenced by many genes, the pathogen strain, fish age and condition, water temperature, nutrition and farm management. Epigenetic patterns may help explain part of the variation between fish, but they should not be treated as a single switch that guarantees resistance. A marker associated with survival in one species or challenge experiment may not work in another species, tissue or production system.

Table 1. Main epigenetic mechanisms and their possible relevance to fish immunity

Mechanism	**How it works**	**Potential relevance to disease resistance**
DNA methylation	Adds methyl groups to DNA; effects depend on genomic location.	May alter expression of genes involved in pathogen recognition, signalling or inflammation.
Histone modification	Changes chemical marks on histone proteins and DNA accessibility.	May make selected immune genes more or less available for transcription.
MicroRNAs and other non-coding RNAs	Regulate messenger-RNA stability or translation.	May fine-tune immune signalling and help prevent excessive inflammation.

Can the environment prepare fish for infection?

Environmental conditions can influence physiology and may also affect epigenetic regulation. Adequate nutrition supplies energy and nutrients needed for immune function and for the biochemical pathways that maintain DNA and histone marks. Temperature affects fish metabolism and immune responses, while poor water quality and chronic crowding can increase stress and reduce resilience. These factors are not epigenetic interventions by themselves; rather, they are management conditions that may interact with epigenetic processes

Researchers are also investigating immune priming: whether a carefully controlled, non-lethal exposure or other stimulus can prepare an animal for a later challenge. In fish, outcomes depend on the species, life stage, stimulus, dose and timing. A priming response should be assessed through controlled studies that measure survival, pathogen load, tissue damage and

immune indicators—not merely changes in gene expression. Epigenetic mechanisms are one possible explanation for some longer-lasting effects, but they are not the only explanation.

Potential applications in aquaculture

1 Supporting selective breeding

Selective breeding programmes aim to produce fish with useful traits, including survival after disease exposure. If robust epigenetic markers are shown to predict resistance across families, generations and farm conditions, they might eventually complement genetic markers and performance records. Validation is essential because epigenetic marks can vary with age, tissue, environment and recent exposure.

2 Improving broodstock and early-life management

Broodstock nutrition, egg quality, incubation conditions and larval rearing all influence early development. Research may identify management practices that support healthy immune development, with epigenetic measurements helping explain how early environments affect later performance. Such practices should prioritise fish welfare and consistent production outcomes.

3 Developing better biomarkers

Epigenetic signatures could potentially be studied alongside blood or mucus indicators, pathogen testing, histopathology and conventional immune measurements. In the future, a validated panel might help distinguish normal variation from physiological stress or infection risk. At present, epigenetic biomarkers for routine farm-side diagnosis of fish disease require further validation and should not replace established diagnostic methods.

Table 2. Possible applications, benefits and cautions

Application	Possible benefit	What must be demonstrated?
Disease-resistance breeding	May add biological information to selection decisions.	Reliable prediction across families, generations and farm environments.
Broodstock and larval management	May help explain how early conditions affect later resilience.	Reproducible improvements in health, survival and welfare.
Immune priming research	May reveal mechanisms	Safe protocols, controlled

	behind a stronger or faster later response.	challenge trials and pathogen-specific evidence.
Health biomarkers	Could complement existing monitoring tools.	Sensitivity, specificity, practical sampling and independent validation.

How do scientists study epigenetic disease resistance?

A typical study compares fish with different disease outcomes under carefully controlled conditions. Researchers may collect relevant tissues before and after infection, measure DNA methylation, profile RNA expression and assess immune or clinical outcomes. Genome-wide methods can identify candidate regions, while targeted assays can test whether those findings are repeatable. Combining epigenetic data with transcriptomics, pathogen load, histopathology and survival provides a stronger picture than relying on one measurement alone.

Good study design is crucial. Researchers should include appropriate controls, replicate groups, standardised infection procedures and clear definitions of resistance and tolerance. Resistance generally refers to limiting pathogen burden, while tolerance refers to limiting damage at a given pathogen burden. Age, sex, family, diet, temperature and sampling time should be considered because they can affect both epigenetic marks and disease outcomes. Most importantly, correlation is not proof of causation: functional experiments are needed to determine whether a candidate epigenetic change actually contributes to protection.

Examples from Important Aquaculture Species

Epigenetic research is relevant to both freshwater and marine aquaculture, although the strength of evidence differs among species. In Nile tilapia, a major farmed fish in many countries, studies of stress, temperature, immune responses and gene regulation can help researchers understand why fish exposed to similar pathogens may show different outcomes. In carp and other freshwater species, investigations of immune-related gene expression and small RNAs provide additional routes for exploring host–pathogen interactions. In salmonids, epigenetic studies have also examined development, environmental adaptation and responses to aquaculture conditions. These examples illustrate the breadth of the field; they should not be interpreted as proof that one epigenetic marker will predict resistance across all species.

For Indian aquaculture, locally important species such as tilapia, rohu, catla, mrigal and freshwater ornamental fishes could be included in future investigations, alongside pathogens

relevant to each production system. A useful study should begin with a clearly defined disease problem—for example, a bacterial outbreak—and compare fish with different clinical outcomes under standardised conditions. Researchers can then ask whether observed epigenetic differences precede infection, arise as a consequence of infection, or reflect differences in stress, nutrition or genetic background.

The Relationship Between Epigenetics, Vaccination and Immune Memory

Vaccination trains the adaptive immune system to recognise particular pathogens or their antigens. Epigenetic regulation may influence how immune cells develop, respond to stimulation and regulate inflammatory signals, but it is not a substitute for antigen-specific immunity. Some research also examines forms of trained innate immunity, in which innate immune cells show altered responses after an earlier stimulus. Such responses have been studied across several animal groups, and the extent and practical value of these effects in different fish species remain areas of investigation.

A key question for fish-health researchers is whether a previous exposure or vaccination is associated with reproducible epigenetic changes that improve protection during a later challenge. To answer this, experiments should include vaccinated or primed groups and suitable controls, measure pathogen burden and survival, and assess tissue damage and immune indicators. The timing of sampling is important because epigenetic patterns can change during infection and recovery. Responsible studies should use approved animal-care procedures and avoid exposing fish to unnecessary disease or stress.

Research Gaps and Priorities

Several questions need to be answered before epigenetic information can be used confidently in disease-resistance programmes. Researchers need reference data for more farmed fish species, standardised protocols for sampling and measuring epigenetic marks, and larger studies that include different families and production environments. Results should be tested in independent populations rather than relying on a single laboratory experiment.

A second priority is to distinguish cause from consequence. Infection itself can change gene expression and epigenetic patterns, so a mark detected after disease may simply reflect the fish's response to illness. Longitudinal studies that sample fish before exposure and at multiple points after infection can help resolve this issue. Functional experiments are also needed to test whether changing a candidate pathway alters the immune outcome.

Finally, researchers should evaluate cost and feasibility. Genome-wide epigenetic assays can generate large datasets, but routine aquaculture decisions require affordable, robust and interpretable tests. Collaboration among fish-health specialists, molecular biologists, geneticists, bioinformaticians and farmers will be important for translating promising findings into useful tools.

Table 3. Key questions for future research

Research question	Why it matters
Do epigenetic marks predict disease outcome before infection?	May help identify early biomarkers rather than consequences of illness.
Are findings consistent across families, ages and farms?	Determines whether a marker can be applied outside one experiment.
Can a candidate mark be shown to affect immunity directly?	Helps distinguish causal mechanisms from simple associations.
Are tests affordable and practical for hatcheries and farms?	Supports realistic translation into fish-health management.

Figure 2. A practical workflow for investigating epigenetic disease resistance

Define fish species and disease problem

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Collect baseline samples and record environment, family and health status

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Conduct controlled challenge study with ethical approval and suitable controls

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Measure clinical outcome, pathogen load and immune indicators

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Profile DNA methylation / histone marks / non-coding RNAs with gene expression

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Validate candidate markers in independent fish populations and farm conditions

Challenges and future prospects

Although epigenetics offers exciting possibilities, several barriers remain. First, evidence is uneven across fish species and pathogens. Second, epigenetic patterns can change over time and differ among tissues, making standardised sampling important. Third, it can be difficult to

separate the effect of an epigenetic mark from the effects of DNA sequence, environment or infection itself. Finally, claims about inheritance must be made cautiously: an effect observed in offspring does not necessarily establish stable transgenerational inheritance.

Future work should focus on economically important species and locally relevant diseases, including bacterial infections that affect freshwater aquaculture. Studies combining epigenomics with whole-genome sequencing, transcriptomics, controlled challenge trials and farm-level validation could help identify useful biomarkers. Researchers should also evaluate cost, animal welfare, feasibility and reproducibility before recommending applications to farmers. Epigenetics is best viewed as a developing tool that may complement vaccination, biosecurity, good nutrition, water-quality management and selective breeding.

Conclusion

Epigenetic regulation provides a link between a fish's genes and its environment. DNA methylation, histone modifications and non-coding RNAs can influence the activity of genes involved in immune defence, potentially contributing to differences in disease resilience. The field may support future advances in breeding, early-life management and health monitoring, but practical use requires strong evidence, functional validation and testing under real aquaculture conditions. For now, epigenetics should complement—not replace—sound fish-health management.

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Volume: 06 Issue No: 10

MILKFISH FOR A CHANGING COAST: A CLIMATE-RESILIENT OPPORTUNITY FOR INDIA'S BRACKISHWATER AQUACULTURE

Article ID: AG-VO6-I10-96

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Abstract

India's brackishwater aquaculture is increasingly exposed to rising temperatures, intense rainfall, cyclones, flooding, salinity instability, and episodes of low dissolved oxygen. These pressures can disrupt pond conditions, weaken fish health, and make production systems that rely on only a few species more vulnerable. Milkfish (*Chanos chanos*) deserves attention as a possible component of a more diversified and climate-aware brackishwater aquaculture sector. The species is euryhaline, meaning it can live across a broad salinity range, and physiological research shows that it can adjust its gill ion-transport systems and energy metabolism when salinity changes. India has also developed hatchery and farming technologies for milkfish, with field demonstrations indicating practical farming potential. However, environmental adaptability should not yet be equated with proven climate resilience. There remains limited species-specific evidence on milkfish performance during heatwaves, hypoxia, and combinations of multiple stressors under commercial pond conditions. Milkfish should therefore be viewed as a promising candidate for research-led diversification, supported by climate-informed farm management and rigorous farm-scale validation.

Introduction

Brackishwater aquaculture is an important livelihood and food-production activity across India's coastal regions. Yet much of the sector remains strongly centred on shrimp farming, making producers vulnerable when disease, market shifts, or environmental shocks affect a single dominant commodity. Diversifying cultured species is therefore not only an economic strategy; it is also a practical way to spread biological and production risks.

Climate change makes this diversification more urgent. Coastal farms are exposed to warmer water, irregular monsoons, flooding, cyclone damage, salinity shifts, and deteriorating water quality. These disturbances can alter pond ecosystems within hours or days, leaving farmers with little time to respond. Reviews of Indian aquaculture identify climate change as a growing challenge for fish physiology, reproduction, production systems, and coastal livelihoods.

Against this background, milkfish (*Chanos chanos*) offers an interesting possibility. Known in many parts of Asia as a hardy, widely cultured finfish, milkfish can inhabit freshwater, brackishwater, and seawater environments. Its ability to regulate salts and water across contrasting environments makes it relevant to coastal areas where rainfall, evaporation, seawater intrusion, and flooding can cause rapid salinity changes. But its promise should be assessed carefully: adaptability is a strong starting point, not proof that the species can withstand every climate-related stress.

Climate Change Is Reshaping Brackishwater Farming

Climate risks in brackishwater aquaculture are rarely isolated. A hot period may increase pond-water temperature, accelerate fish metabolism, and reduce dissolved oxygen at the same time. Heavy rainfall can abruptly dilute pond salinity, while floods may introduce sediment, pollutants, predators, and pathogens. Cyclones can damage bunds, screens, sluice gates, power supplies, and aeration systems, often when farms most need active water-quality management.

Indian coastal aquaculture assessments have documented how cyclones, floods, and salinity alterations can damage facilities and disrupt production. Wider reviews similarly identify temperature change, altered freshwater inputs, saline intrusion, storms, and water-quality deterioration as linked risks for coastal and brackishwater farming.

Low dissolved oxygen is particularly important. Warm water holds less oxygen, while fish require more oxygen as metabolic demand rises. Dense stocking, algal blooms, organic loading, and cloudy conditions can make the problem worse. During such events, fish may reduce feeding, become stressed, grow slowly, or die. The central challenge for climate-resilient aquaculture is therefore not merely choosing a “tolerant” species, but matching suitable species with robust pond design, monitoring, aeration, emergency planning, and appropriate stocking density.

Why Milkfish Merits Attention

Milkfish is a euryhaline fish: it can survive and grow across a wide range of salinities. This trait has clear relevance for brackishwater farming, where salinity can vary seasonally or change suddenly after rainfall, flooding, or seawater intrusion. Physiological studies show that milkfish actively adjusts its osmoregulatory machinery when transferred among fresh, brackish, and seawater conditions. In particular, the fish's gills modify sodium–potassium ATPase activity and related ion-transport processes, enabling it to maintain internal salt and water balance under changing external salinity. This capacity has practical significance. Salinity is not simply a number on a farm logbook; it determines how much energy a fish must devote to maintaining its internal balance. Research on milkfish indicates that salinity can influence growth, metabolism, energy use, and physiological responses to temperature stress.

Milkfish is also not an unfamiliar species in India. ICAR–Central Institute of Brackishwater Aquaculture has developed seed-production and farming technologies for milkfish as part of its broader effort to diversify brackishwater finfish aquaculture. Demonstrations in Pulicat, Tamil Nadu, have shown that nursery rearing followed by brackishwater pen culture can be technically feasible and economically viable under local conditions.

Environmental Adaptability Is Not the Same as Proven Climate Resilience

The idea of milkfish as a climate-resilient species is attractive, but it needs precise framing. Milkfish has established biological attributes, especially euryhalinity and a demonstrated ability to adjust osmoregulatory and metabolic processes. These traits make it a credible candidate for further climate-resilience research.

However, it would be premature to claim that milkfish is already proven to be resilient to warming, hypoxia, cyclones, or all combinations of climate stressors in Indian ponds. Climate resilience involves more than surviving a short-term environmental change. It includes maintaining feeding, growth, immune competence, reproduction, welfare, and economic performance during and after disturbance.

For example, experimental studies show that both temperature and salinity influence milkfish energy metabolism. Under low-temperature stress, freshwater-acclimated and seawater-acclimated milkfish show different patterns of glycogen use, mitochondrial metabolism, and oxidative stress responses. These findings demonstrate physiological flexibility, but they also

show that an environmental challenge may become more or less stressful depending on the salinity to which fish are acclimated. This lesson is important for farmers: there may be no single "safe" salinity or temperature for milkfish. Instead, resilience may depend on the rate of environmental change, fish size, nutritional condition, stocking density, disease status, and the interaction between temperature, salinity, and dissolved oxygen.

Heat, Salinity Fluctuations, and Hypoxia: What We Know and What We Need to Know

Heat stress

Rising temperatures and marine heatwaves are major concerns for all tropical aquaculture. Milkfish is naturally associated with warm-water environments, which suggests relevance for tropical farming. Yet the limits of tolerance matter. A fish can survive high temperatures for a short period while still experiencing reduced appetite, impaired growth, elevated stress hormones, or increased disease susceptibility.

Available milkfish research has examined thermal stress responses and temperature-dependent physiological changes, but more work is needed to establish clear upper thermal limits for strains cultured in Indian conditions. Studies should distinguish between short-term survival and sustained farm performance.

Salinity variability

This is the area in which milkfish has its strongest biological case. Its euryhaline nature and well-documented gill-based osmoregulatory responses indicate an ability to cope with contrasting salinity environments. For climate-resilient brackishwater farming, the key question is not whether milkfish can exist in different salinities. It is whether it can maintain growth and health when salinity changes rapidly as may happen after extreme rainfall, flooding, or prolonged evaporation. Research should test realistic rates of salinity change rather than only comparing fish held at stable freshwater and seawater conditions.

Hypoxia

Hypoxia, or low dissolved oxygen, is likely to become more frequent when high temperatures, eutrophication, heavy rain, and pond stratification occur together. There is a need for targeted research on milkfish responses to low oxygen under different temperatures and salinities. Milkfish's metabolic flexibility may be relevant here, but direct evidence on hypoxia tolerance thresholds, behavioural warning signs, recovery after oxygen depletion, and long-term

production consequences remains insufficient for strong farm recommendations. This is a critical evidence gap because low oxygen events can cause rapid losses even in otherwise robust species.

Integrating Milkfish into Climate-Resilient Farming Systems

Milkfish should be considered as part of a broader climate-resilient farming strategy rather than as a stand-alone solution. Its potential value lies in diversification: adding a suitable finfish option to reduce dependence on a narrow production base and to create opportunities in ponds, pens, and other brackishwater systems where local conditions and market access are favourable.

Integration should be guided by site-specific planning. Farmers and extension agencies need to consider water source, seasonal salinity range, temperature profile, flood risk, pond depth, seed availability, feed requirements, market demand, and post-harvest handling. The presence of fine intermuscular bones has historically limited consumer acceptance, although recent Indian efforts in deboning and value addition seek to improve marketability.

Climate-informed management is equally important. Farms considering milkfish should incorporate:

- routine monitoring of temperature, salinity, dissolved oxygen, pH, and ammonia;
- early-warning systems for extreme rainfall, cyclones, and heat events;
- emergency aeration and backup power;
- stocking densities matched to pond carrying capacity;
- gradual acclimation when salinity changes are unavoidable;
- stronger pond embankments, screened water inlets, and drainage planning; and
- harvest, transport, and marketing plans that reduce losses after climate-related disruptions.

These measures will benefit milkfish farming, but they are also essential for any coastal aquaculture system facing more variable environmental conditions.

Research Priorities Before Large-Scale Promotion

Milkfish has enough promise to justify focused research, but large-scale promotion should follow evidence rather than assumption. Priority studies should address:

1. Thermal limits and performance: Determine survival, feeding, growth, stress, and disease outcomes across realistic heatwave scenarios.

2. Hypoxia thresholds: Establish the dissolved-oxygen levels at which milkfish reduces feeding, experiences physiological stress, loses growth, or suffers mortality.
3. Combined-stressor experiments: Test temperature × salinity × oxygen interactions, because real ponds experience multiple stressors simultaneously.
4. Acclimation and recovery: Measure how quickly fish recover after sudden rainfall, salinity dilution, heat exposure, or low-oxygen episodes.
5. Farm-scale validation: Compare productivity, profitability, health, and risk profiles across seasons and regions under commercial farming conditions.
6. Genetic and seed-quality studies: Assess whether different broodstock sources or hatchery-reared populations vary in stress tolerance and production performance.
7. Consumer and value-chain development: Evaluate processing, deboning, product development, market acceptance, and price stability alongside biological performance.

Conclusion

Milkfish has genuine potential as a candidate species for climate-resilient brackishwater aquaculture in India. Its ability to live across different salinities, its physiological capacity for osmoregulatory adjustment, and the availability of emerging Indian culture technologies make it a valuable option for diversification. Yet milkfish should not be presented as a guaranteed climate-proof alternative. Its resilience to high-temperature events, hypoxia, and interacting environmental stressors must be demonstrated under realistic pond conditions. The most responsible path forward is to combine species diversification with climate-smart farm management and systematic research. If these steps confirm strong performance, milkfish could become an important part of a more adaptable, diversified, and sustainable brackishwater aquaculture sector.

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Volume: 06 Issue No: 10

FIFTY RICE LANDRACES OF TAMIL NADU

Article ID: AG-VO6-I10-97

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Introduction

Tamil Nadu grows rice across approximately 17 lakh hectares in multiple cropping seasons shaped by two monsoons the southwest (June–September) and northeast (October–January). The state's rice calendar comprises eight distinct seasons: Navarai, Sornavari, Kar, Kuruvai, Early Samba, Samba, Late Samba, and Thaladi. The Samba season (August sowing, January harvest) is the dominant season, aligned with the northeast monsoon and responsible for the richest, longest-duration traditional varieties. The Kuruvai (June–July sowing, 90–120 days) and Navarai (December–January sowing) seasons permit short-duration varieties and double-cropping. A total of 136 landraces of Tamil Nadu has been catalogued and characterized by TNAU researchers. According to the review by Tamil Nadu Agricultural University, over 400 landraces were recorded in Sangam literature and Vedic agricultural texts. The Namma Nellu (Our Rice) programme of CIKS has documented over 170 traditional varieties still in cultivation across Tamil Nadu, with active seed banks, farmer producer companies, and direct buyer networks being built to sustain their commercial viability.

FIFTY RICE LANDRACES OF TAMIL NADU

The following are the most important rice landraces specifically belonging to the state of Tamil Nadu and their characteristics are discussed as hereunder.

1. Ambasamudaram: It is highly valued for its excellent cooking and processing qualities, particularly for preparing traditional South Indian foods such as idli and dosa, as the grains produce a soft texture and ferment well. The rice is generally medium-sized with good milling recovery, and the parboiled grains retain desirable cooking characteristics, including softness, pleasant taste, and easy digestibility. Cultivated mainly under irrigated conditions, This rice is well adapted to the agro-climatic conditions of southern Tamil Nadu and is appreciated by farmers for its stable yield and by consumers for its superior grain quality. It is a long duration cultivar; ~180 days; harvested during Jan–Feb	
2. Annaikomban: This is an awned variety and gets its name because of this. It is a long slender white rice that matures in 140-150 days and suitable for samba season. The grains are lengthy like basmati and are suitable for cooking rice. It can easily digestibile, cures constipation, removes toxic substances. The cooked rice has long shelf life and so it is often preferred during journey.	
3. Aravan Kuruva: This is a traditional rice landrace cultivated primarily in Tamil Nadu under rainfed and low-input conditions. It is valued for its adaptability to marginal soils and erratic rainfall, making it suitable for sustainable farming systems. The variety possesses moderate tolerance to drought stress and produces medium-sized grains with satisfactory cooking quality. Farmers prefer Aravan Kuruva because of its stable performance under adverse environmental conditions and its ability to maintain yield without intensive fertilizer application.. This is a short/medium duration cultivar.	

4. Arcot Kichili Samba: This rice originated from the Arcot region of Tamil Nadu and is recognized for its excellent grain appearance and consumer preference. The variety performs well under irrigated conditions and produces fine grains with desirable cooking characteristics. It possesses moderate resistance to lodging and stable yield performance under traditional cultivation. Suitable for amba season, sown Sep–Jan with a duration of 150-180 days.	
5. Ariyan Nel: This is an indigenous rice variety traditionally grown in Tamil Nadu for its adaptability and stable grain production. It is characterized by medium-duration maturity and good performance under traditional cultivation practices. The variety exhibits adaptability to local agro-climatic conditions and contributes to the conservation of genetic diversity in rice. Ariyan Nel is recognized for its acceptable grain quality and is maintained by farmers as an important landrace because of its resilience to variable environmental conditions. It is a long duration cultivar with 150–180 days suitable for Samba season.	
6. Arupatham Kuruvai: This is a non-lodging very short duration of 60-70 days maturing Kuruvai and Navarai season cultivar. The paddy is yellow in colour, while grain is red in colour. The grain is short bold and easy to thrash. It has high fiber content and usually given for clearing constipation and also for neuro patients.	
7. Arubatham Samba: This is a traditional Samba-season rice variety maturing in approximately 150–160 days. It performs well under irrigated as well as rainfed conditions and produces medium-slender grains with desirable cooking quality. The most notable characteristic of this variety is its stable grain yield during the long-duration Samba season despite environmental	

fluctuations. Its adaptability and grain quality have ensured its continued cultivation by traditional farmers. It is suitable for Kar/Kuruvai seasons with a duration of 110-120 days.	
8. Attur Kichili Samba: This is a regional selection of Kichili Samba traditionally cultivated around Attur in Tamil Nadu. The variety produces fine, slender grains with excellent cooking quality, soft texture, and pleasant taste. It is well adapted to irrigated ecosystems and matures in about 135–145 days. The variety is highly preferred for preparing premium-quality cooked rice and serves as an important donor for grain quality improvement. This is suitable for samba season with a duration of 150-180 days.	
9. Garudan Samba: This is named after Garuda, the mythological eagle vehicle of Lord Vishnu — is one of the most distinguished and culturally revered Samba landraces of the Cauvery delta. The name Garuda connotes both speed and divine strength; the variety lives up to its name with a vigorous growth habit and long, slender, elegant grains that are considered among the finest in the Tamil Nadu delta rice tradition. A long-duration (150-165 days) photosensitive variety, fits the classic Samba season calendar and has been grown for generations in the highly fertile fields of Thanjavur, Tiruvarur, and Nagapattinam. Its long slender grains cook to a soft, slightly sticky texture with mild fragrance — ideal for curd rice, Pongal, and temple prasadam	
10. Iluppaipoo Samba: This is named after Mahua tree (Madhuca longifolia) and "Poo" meaning flower — takes its name from the distinctive floral fragrance of Mahua blossoms that the grains emit when cooked. A medium-grain rice with a naturally pinkish hue from its bran layer, Iluppaipoo Samba is one of the most fragrant and visually distinctive of Tamil Nadu's traditional delta landraces. Cultivated in the Samba season in	

Thanjavur and Tiruvarur districts, it carries the hallmarks of a premium aromatic rice: subtle floral fragrance, slightly sweet flavor, and soft texture after cooking. Rice connoisseurs describe it as one of the most distinctive aromatic experiences in South Indian rice heritage. It has a duration of 135-150 days.	
11. Kadikazhuthan: This is a traditional rice landrace cultivated mainly under rainfed ecosystems. It possesses vigorous plant growth, good tillering ability, and moderate drought tolerance. Its most important feature is its strong adaptation to moisture-deficit environments through vigorous vegetative growth and efficient water utilization. This characteristic makes it valuable for breeding climate-resilient rice cultivars. It is suitable for Kar/Kuruvai seasons with 110-120 days duration.	
12. Kaivara Samba: This is a traditional Samba-season rice variety cultivated in Tamil Nadu under conventional farming systems. It possesses medium-duration maturity and stable productivity under moderate water availability. Its distinguishing feature is its reliable performance under traditional cultivation with minimal fertilizer input while maintaining satisfactory grain quality. The variety is an important source of adaptive genes for sustainable rice breeding. It is suitable for Samba/rainfed season, and sown in Aug–Sep with 150-180 days duration.	
13. Kalarpalai: This is a traditional rice landrace cultivated in the saline and alkaline ("kalar") soils of Tamil Nadu. The variety has evolved under adverse soil conditions and exhibits excellent adaptability to sodic and salt-affected lands where modern high-yielding varieties often fail. It is a medium-duration cultivar with moderate tillering ability and stable grain production under low-	

input management. The grains possess acceptable cooking quality and are traditionally used for household consumption. Due to its natural adaptation to problematic soils, Kalar Palai is considered an important genetic resource for breeding rice varieties with improved salinity and alkalinity tolerance. It matures in 150-180 days.	
14. Kaliyan Samba: This is a traditional Samba-season rice variety cultivated mainly in Tamil Nadu under rainfed and irrigated ecosystems. It is characterized by medium-tall plants, strong stems, and stable productivity under traditional cultivation practices. The variety possesses good adaptability to environmental fluctuations and produces medium-sized grains with satisfactory cooking quality. Farmers have traditionally preferred Kaliyan Samba because of its reliable yield and ability to withstand moderate drought during the reproductive stage. The variety serves as a valuable source of adaptive genes for climate-resilient rice breeding. It is suitable for samba season, with 150-170 days duration.	
15. Kallimadayaan: This is an indigenous rice landrace maintained by farming communities because of its adaptability to low-input agricultural systems. The variety performs well under rainfed ecosystems and requires comparatively fewer external inputs than modern cultivars. It produces medium-sized grains with acceptable cooking quality and demonstrates moderate tolerance to drought stress. The landrace possesses considerable genetic diversity, making it valuable for conservation and crop improvement programmes focused on abiotic stress tolerance. It is suitable for samba season, with 150-170 days duration.	

16. Kalurundai: This is, also known as Kallundai, is a traditional rice variety recognized for its distinctive bold, round grains. It is generally cultivated under irrigated conditions and exhibits good plant vigour with satisfactory tillering capacity. The variety produces consistent yields under traditional farming systems and is appreciated for its grain texture and cooking quality. Kalurundai contributes valuable genetic diversity for grain morphology and quality traits in rice breeding programmes. It is suitable for samba season, with 150-170 days duration.	
17. Kandasali: This is an indigenous rice landrace traditionally cultivated in Tamil Nadu under conventional farming systems. It is known for its medium-duration growth habit, satisfactory tillering, and adaptation to local agro-climatic conditions. The variety exhibits stable grain production under moderate moisture availability and possesses acceptable grain quality suitable for traditional food preparations. Owing to its broad adaptability, Kandasali is regarded as a useful genetic resource for improving yield stability under variable environments. It is suitable for samba season with 150-170 days duration.	
18. Kappakar: This is a traditional rice variety cultivated mainly under rainfed ecosystems where water availability is limited. It demonstrates moderate drought tolerance, efficient nutrient utilization, and satisfactory grain production under low-input farming systems. The variety possesses medium-sized grains with acceptable cooking quality and has been maintained by farmers because of its resilience to environmental stress. Kappakar represents an important source of genes for breeding drought-resilient rice cultivars. It is suitable for samba season with 150-170 days duration.	

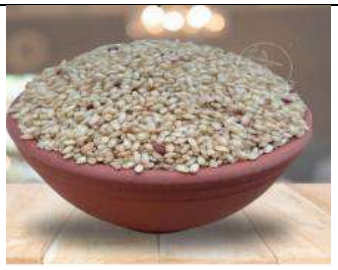
19. Karungkuruvai: This is one of the most famous traditional medicinal rice landraces of Tamil Nadu. The variety produces dark-coloured grains rich in antioxidants, iron, zinc, and phenolic compounds. Traditionally, Karungkuruvai rice has been consumed for improving immunity and general health, and it is widely used in Siddha and Ayurvedic medicinal preparations. The variety exhibits good tolerance to drought and moderate resistance to pests and diseases, making it suitable for organic farming systems. Its high nutritional value and medicinal importance have attracted considerable attention in rice nutritional research**.** It is suitable for kuruvai season with 120 days duration.	
20. Karuppu Kavuni: This is one of the most renowned traditional black rice landraces of Tamil Nadu. The variety produces deep black to purple grains rich in anthocyanins, phenolic compounds, iron, zinc, and dietary fibre, making it highly nutritious. Historically, it was considered a royal rice because of its exceptional nutritional and medicinal properties. Karuppu Kavuni exhibits moderate tolerance to drought and common diseases while performing well under organic cultivation. The grains possess a distinctive nutty flavour and are widely used in traditional desserts and health foods. Owing to its high antioxidant content, Karuppu Kavuni is increasingly utilized in breeding programmes aimed at improving nutritional quality. It is suitable for samba season with 150-170 days duration.	

21. Karunkuruvai: "Karun" meaning black/dark and "Kuruvai" referring to the short Kuruvai cropping season is a traditional short-duration dark-grain rice of Tamil Nadu, belonging to the "Kuruvai" category of varieties that ripen quickly enough to fit the June–September cropping window. Like other Kuruvai rices, Karunkuruvai allows farmers to complete a rice crop before the Samba season begins, enabling double-cropping in the Cauvery delta. The grains are distinctly dark reddish-black, short, and bold. With a crop duration of 105–115 days, fits neatly within the Kuruvai season window. It is rich in anthocyanins, iron, and antioxidants — and is traditionally used as a medicinal food.	
22. Karuthakkar: This is a traditional rice landrace cultivated under rainfed conditions in Tamil Nadu. It exhibits vigorous vegetative growth, moderate tillering ability, and satisfactory grain production under low-input farming systems. The variety adapts well to moisture-deficit environments and produces medium-sized grains with acceptable cooking quality. Its genetic diversity and resilience under traditional cultivation make it an important germplasm resource for breeding climate-resilient rice cultivars. It is suitable for Kar season with 110-120 days duration.	
23. Kattuyanam: "Kattu" meaning forest/wild and "Yanam" meaning elephant in Tamil. A tall, ancient, photosensitive variety that can grow to 5–6 feet in height, the plants form such a dense, tall canopy that the variety was said to be tall enough to hide an elephant inside the field. The grains are long, reddish, and unpolished, with a firm texture and robust flavor. It requires almost no inputs: once seeds are sown, farmers simply leave the crop to grow and return only for harvest — a remarkable example of self-reliant agriculture. It is naturally pest- and disease-resistant, weed-suppressive due to its tall stature. It is	

traditionally consumed as parboiled rice and it is taken for diabetics. It is suitable for samba season with 150-180 days duration.	
24. Kichedi Samba: This is a traditional rice variety appreciated for its soft grains and suitability for preparing porridge, khichdi, and other traditional foods. It performs well under irrigated cultivation and produces satisfactory yields under moderate fertilizer application. The variety possesses acceptable grain quality and contributes to the conservation of traditional culinary rice diversity. It is suitable for samba season with 150-180 days duration.	
25. Kallan Samba: This is a traditional rice landrace cultivated in Tamil Nadu under both irrigated and rainfed conditions. It possesses medium-duration maturity, stable tillering ability, and satisfactory grain quality. The variety adapts well to conventional farming systems and demonstrates stable grain production under varying climatic conditions. Its genetic diversity makes it useful for rice improvement programmes. It is suited for samba season with 150-170 days duration.	
26. Kudaivazhai: This is a traditional rice variety recognized for its distinctive plant architecture and adaptability to local cultivation systems. The variety grows vigorously under irrigated conditions and produces medium-sized grains with desirable cooking quality. It is valued for its stable productivity and contribution to the conservation of indigenous rice biodiversity. It is suited for samba season with 150-180 days duration.	

27. Kullakar: This is a short-statured variety with deep red grains rich in iron, zinc, dietary fibre, and antioxidants. The variety possesses excellent drought tolerance, strong root development, and efficient water-use efficiency, making it particularly suitable for rainfed agriculture and direct-seeded rice systems. It is also highly valued in organic farming because of its ability to suppress weeds through rapid early growth and its superior nutritional quality. It is suited for samba season with 150-170 days duration.	
28. Kunthali: This is an indigenous rice landrace cultivated under traditional farming systems in Tamil Nadu. It exhibits moderate drought tolerance, satisfactory tillering ability, and adaptability to low-input cultivation. The variety produces medium-sized grains with acceptable cooking quality and contributes to the conservation of indigenous rice genetic resources. It is suitable for samba season with 150-170 days duration.	
29. Kuruvai: This is a traditional short-duration rice cultivated during the Kuruvai season (June–September) in the Cauvery delta. The variety matures rapidly, allowing efficient utilization of early irrigation water and facilitating multiple cropping. It produces acceptable grain yields and adapts well to irrigated ecosystems. It is suitable for kuruvai season with 120 days duration.	

30. Kuthiraival Samba: This is a traditional Samba-season rice variety named after its long awns resembling a horse's tail ("Kuthirai Vaal" in Tamil). The variety possesses tall plants, strong stems, and medium-sized grains with satisfactory cooking quality. It adapts well to traditional irrigated cultivation and maintains stable productivity under seasonal climatic variations. The long awns also help distinguish the variety morphologically in germplasm collections. It is suitable for samba season with 150-170 days duration.	
31. Kuzhiyadichan: This is a traditional rice landrace cultivated in Tamil Nadu under rainfed and low-input farming systems. The variety is well adapted to marginal soils and exhibits stable grain production despite fluctuations in rainfall. It possesses medium-duration maturity (150-180 days), moderate tillering ability, and satisfactory grain quality suitable for traditional food preparations. The landrace represents an important source of genetic diversity for improving drought adaptation in rice breeding programmes during samba season.	
32. Kothamalli samba: It has a short bold or round bold resembling the coriander seed, with a reddish-brown or brownish rice appearance. It is known for its distinctive aroma and pleasant taste when cooked. The cooked rice has a firm texture and suitable for daily meals. It has a duration of 135-140 days and can be cultivated during samba season. It is having drought tolerance. It has medicinal properties to stop bleeding from injuries and also recommended for weight reduction and diabetic patients.	

33. Mappillai Samba: This is one of the most famous traditional red rice varieties of Tamil Nadu. The variety derives its name from the Tamil tradition in which newly married grooms ("Mappillai") consumed this rice to improve strength and endurance. It is a tall, long-duration landrace producing red grains rich in iron, zinc, dietary fibre, antioxidants, and polyphenols. It exhibits excellent drought tolerance, vigorous root growth, and strong resistance to lodging, making it highly suitable for rainfed and organic farming systems. It is suitable for samba season with 180 days duration.	
34. Mattakaar: This is characterized by medium-duration maturity, vigorous vegetative growth, and satisfactory grain yield. The variety performs well under irrigated as well as rainfed conditions and produces medium-bold grains with acceptable cooking quality. Its adaptability to different cultivation environments makes it an important genetic resource for rice improvement. It is suitable for samba season with 150-180 days duration.	
35. Nalla Mani Samba: This is a traditional Samba-season rice variety recognized for its attractive, pearl-like grains and excellent cooking quality. The variety matures in about 140–150 days and performs well under irrigated ecosystems. It possesses moderate resistance to lodging and stable grain yield under conventional cultivation. The fine grain appearance and desirable texture after cooking have contributed to its popularity among traditional farming communities. This is suitable for samba season with 150-170 days duration.	

36. Neelan Samba: This is a traditional rice variety cultivated during the Samba season in Tamil Nadu. The variety is characterized by tall plants, moderate tillering ability, and stable productivity under irrigated cultivation. It adapts well to seasonal climatic changes and produces medium-slender grains with satisfactory cooking quality. Neelan Samba represents an important component of the indigenous rice gene pool maintained by farmers. This is suitable for samba season with 150-180 days duration.	
37. Nootripathu: This variety exhibits vigorous vegetative growth, stable tillering, and moderate resistance to lodging. It produces medium-sized grains with acceptable cooking quality and demonstrates reliable productivity under irrigated conditions. The variety is conserved as a valuable genetic resource because of its adaptability and agronomic stability. This is suitable for Kar/rainfed season with 110 days duration,	
38. Norungan; This is suitable for Kar season under rainfed farming systems because of its adaptability to moisture-limited environments. It has 1110-120 days maturity, satisfactory tillering ability, and acceptable grain quality. The variety performs consistently under low external input agriculture and contributes useful genes for drought adaptation and environmental resilience.	

39. Poongkaar: This is a highly valued traditional red rice variety of Tamil Nadu, particularly recognized for its nutritional and medicinal importance. The variety is rich in iron, minerals, antioxidants, and dietary fibre and has traditionally been recommended for women, especially during pregnancy and lactation. It exhibits excellent drought tolerance, deep root development, and good adaptation to organic farming systems. It produces red grains with superior nutritional quality and contributes significantly to sustainable agriculture and nutritional security. It is suitable for Kar and Samba season with 150-180 days duration.	
40. Poovan Samba: This is a traditional Samba-season rice variety producing fine grains with desirable cooking quality and pleasant taste. It performs well under irrigated ecosystems and matures in approximately 150–180 days. The variety exhibits stable productivity, moderate resistance to lodging, and adaptability to seasonal climatic variations. Its grain quality has made it a preferred traditional variety for household consumption. This suitable for samba season.	
41. Rathasali: This is a traditional red-grained rice landrace cultivated in parts of eastern and southern India. The variety is distinguished by its reddish pericarp, which is rich in anthocyanins, iron, zinc, dietary fibre, and phenolic compounds, contributing to its high nutritional and antioxidant value. In traditional Ayurvedic literature, it is regarded as a medicinal rice and has been recommended for improving blood health, enhancing immunity, and aiding post-illness recovery. It exhibits moderate tolerance to drought and common pests and diseases while producing grains with good cooking quality and a pleasant taste. It is suitable for samba season with 145-160 days duration.	

42. Sandikaar: This is an indigenous rice landrace cultivated under traditional farming practices. It demonstrates moderate tolerance to environmental stresses and performs consistently in rainfed ecosystems. **Its characteristic feature is its adaptability to marginal cultivation conditions with minimal agricultural inputs.** The variety also possesses acceptable grain quality and contributes to on-farm conservation of rice biodiversity. This is suitable for Samba/rainfed season, sown Aug–Sep, with a duration of 150–180 days	
43. Semballai: This is a short duration cultivar with 100-105 days duration suitable for direct sowing in semidry condition during samba season. It is drought tolerant. The pericarp colour is red and the grain is dull white. It is recommended for infants and highly preferred by juveniles for its easy digestibility.	
44. Soorakuruvai: The paddy has yellowish brown ridges with dark brown grain. It is medium bold grain type. It is suitable for Kuruvai and Navarai seasons. This rice ie recommended for pregnant and lactating women. It is rich in Magnesium, Iron, Calcium, Potassium and Zinc.	
45. Seeraga Samba: This is named after "Seeragam" (cumin) for its unmistakable resemblance to cumin seeds in size, shape, and aroma is the undisputed king of Tamil Nadu's aromatic rice tradition. These small, ovular, fine-grained white kernels carry a naturally fragrant, starchy quality that makes them the first choice for Tamil Nadu's world-famous biryanis. Grown during Samba season with 120-130 days duration. The variety also holds deep ritual importance — it is the rice of choice for Thai Pongal celebrations and temple offerings. Rich in selenium (shown to help prevent colon and intestinal cancers), phytonutrients with anticancer properties, and a low glycaemic	

index, Seeraga Samba is both a gastronomic and nutraceutical treasure.	
46. Sivappu Kuruvikar: The grain contain appreciable amounts of iron, antioxidants, and dietary fibre, contributing to their nutritional value. The variety demonstrates good drought tolerance, vigorous early growth, and adaptability to low-input farming systems. It is highly suitable for organic cultivation and is conserved as an important genetic resource for improving nutritional quality and climate resilience in rice. Suitable for kuruvai season with 120 days duration.	
47. Thanga Samba: "Thanga" meaning gold in Tamil — earns its name from the golden-yellow color of its grain, which shimmers in the husk like 22-carat gold. A long-duration (140-155 days) Samba season cultivar of the Cauvery delta, Thanga Samba is one of Tamil Nadu's most aesthetically distinctive heritage varieties. The grains are long and slender, with a golden sheen that persists even after light milling. Its flavor is mild, slightly nutty, and fragrant.	
48. Thooyamalli: The name "Thooyal" meaning pure/white and "Malli" meaning jasmine in Tamil — is Tamil Nadu's classic fine-grain, slender, aromatic white rice. With long, elegant, pure-white kernels and a subtle jasmine-like fragrance when cooked, It has been the rice of choice for temple offerings, wedding feasts, and festive meals across Tamil Nadu for centuries. A Samba season variety with 125-135 days duration has a relatively low glycaemic index for a white rice, making it a preferred choice for people managing blood sugar. It is particularly prized for making South Indian tiffin items (Idli, dosa batter) and traditional preparations like Chakra Pongal and curd rice.	

49. Valan Samba: This is a long duration (140-150 days) variety suitable for transplanting as well as direct seeding for samba season.It is an awned variety having flood tolerance as well as drought. This rice is suitable for idli making. It has property of cleansing the digestive tract and can improve physical health. It has higher levels of iron, magnesium and zinc. The paddy is straw in colour, while grain is red in colour.	
50. Vasanai Seeraga Samba: This is a short duration (110-120 days duration) suitable for samba season for transplanting condition. The rice grain is very fine and slender and dull white in colour. The cooked rice is very tasty and has a characteristic fragrance and is suitable for variety rice preparations. It is easily digestible, regulate and induces appetite.	

Conclusion

Despite their agronomic resilience and nutritional value, most Tamil Nadu rice landraces remain confined to small farmer-held pockets, and duplications across differently-named accessions complicate systematic conservation. Molecular and morphological (DUS) characterization to resolve synonymy, document genetic diversity, and identify donor lines for breeding programmes targeting drought, salinity, sodicity, submergence and pest resistance. Landraces such as Norungan and Nootripathu have already served as parents in QTL-mapping studies for drought tolerance, while Kattuyanam (*via* TNR 2) and Kichili Samba (*via* GEB 24) have contributed directly to released high-yielding cultivars — underscoring the continuing breeding value of this rapidly eroding genetic resource.

The landrace rice varieties of Tamil Nadu constitute a vast, underutilised reservoir of genetic diversity shaped by centuries of farmer selection and documented in continuous Tamil literary tradition from the Sangam period onward. While detailed, variety-specific agronomic data (precise seed rate, sowing date, spacing) remain unpublished for the majority of the roughly 100–150 landraces still in cultivation, the broader seasonal and duration-class framework presented here, combined with documented nutritional, therapeutic and stress-tolerance traits for

the better-studied varieties, provides a usable agronomic and ethnobotanical reference. Continued systematic characterization, molecular fingerprinting to resolve duplicate accessions, and on-farm conservation are essential to prevent further genetic erosion and to fully harness these landraces for climate-resilient and nutritionally secure rice breeding in the future.

Volume: 06 Issue No: 10

TREND PERFORMANCE OF INDIAN FLOWER EXPORTS: A CONCERN FOR DIVERSIFYING OUR INTERNATIONAL TRADE

Article ID: AG-V06-I10-98

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Abstract

At the Asian level, India ranks 2nd after China in floriculture production, highlighting a tremendous opportunity to expand and diversify international markets. During 2023-24, India produced 3.2 million tonnes of flowers and exported 19,677.89 MT of floriculture products. This study captures the export trend of Indian flower exports (HS code: 0403) during the period from 2013-14 to 2023-24. The collected data from APEDA were analysed using an exponential function. Results revealed that the major importers of Indian flowers are the USA, the UK, the UAE, and Malaysia. The growth rate of export volume and value exhibited negative and significant results, while countries like Nepal and Spain showed the highest growth among all markets. A negative growth of flowers export from India is a matter of concern for policy maker to sustain and diversified our international trade along with maintaining quality standards and trade competitiveness.

Key words: India, Export, Flowers, Growth rate, Destination pattern.

Introduction

Since ancient times, flowers have held aesthetic and religious value. They were used as symbols of purity and beauty, for ornamental purposes and social ceremonies, etc. As a result, in the present scenario, the trading of flowers has become a booming industry in the world. Worldwide, more than 120 countries are involved in the commercial production and exporting of flowers. The Netherlands, Colombia and the EU are the top exporters, and Germany, France, the United States of America, *etc*., are top importers in the world. This scenario in international trade opens new business opportunities for the country. So, the government of India has opened the

door for exports because India has diverse agro-climatic conditions that are suitable for flower production (Misra and Ghosh, 2016)

In 2023-24, 297 thousand hectares of area were under cultivation for flowers, which produced 2284 thousand tonnes of loose flowers and 947 thousand tonnes of cut flowers in India. The country has exported 19677.89 MT of floriculture products to the world worth Rs. 717.83 Crores/86.63 USD million, in which flowers (HS code: 0603) contribute 9107.52MT of volume and value of Rs. 195.94 Crores/23.64 USD million (APEDA). United States of America, the Netherlands, and the United Arab Emirates were major importing countries of Indian floriculture. Tamil Nadu, Karnataka, Gujarat, Uttar Pradesh, Assam and Maharashtra have emerged as major floriculture centres.

Objective

1. To estimate the growth rates of quantity, value and price of flower exports from India to major countries;
2. To study the destination pattern of flower exports from India;

Research Methodology

The time series data on exports of flowers from India was collected for the period of 2013-14 to 2023-24 from annual published information on the Agricultural and Processed Food Products Export Development Authority (APEDA), Ministry of Commerce and Industry, Directorate General of Commercial Intelligence and Statistics (DGCIS) and its website. The top countries were selected based on the past ten years' performance in terms of value of export of it. The compound growth rates were calculated for the average quantity of flower exports, its value and price by fitting the exponential function of the form. $Y = a\, b^t e^u$ where Y is the dependent variable, a is the intercept, b is the regression coefficient, t is the time period in years, and e^u is the error term.

Results

Table 1 represents the growth trend in quantity, value and price of flower exports from India. The results of selected top 20 countries revealed that the overall growth in terms quantity, value and price of flowers exports is -5.89, -5.08 and 0.86 per cent, respectively, displaying a slight decline in quantity and value export but increasing in prices of export. These results conform with the findings of Pavithra *et al.* (2016). They found that the growth of the quantity of exports by India was -03.68 per cent per annum during 2004-05 to 2013-14.

Table 1: Annual compound growth rates of quantity, value and price of flower exports from India to major countries (2013-14 to 2023-24)

No.	Country	Quantity (MT)		Value (Rs. Lacs)		Price (Rs. Lacs / MT)	
		CAGR%	SE	CAGR%	SE	CAGR%	SE
1	U. S. A.	-14.65 ***	1.48	-2.91	1.80	13.75 ***	0.55
2	U. K.	-22.02 ***	1.15	-10.69 ***	1.00	14.54 ***	0.62
3	U. A. E.	6.05 ***	1.00	5.21 ***	0.94	-0.80	0.79
4	Malaysia	18.22 ***	1.68	15.21 ***	1.32	-2.54 ***	0.84
5	Singapore	9.38 ***	0.96	5.86 ***	0.86	-3.20 ***	0.82
6	Germany	-34.70 ***	0.71	-30.62 ***	0.96	6.25 ***	1.17
7	Netherland	-29.34 ***	2.35	-13.73 ***	4.04	22.09 ***	2.31
8	Australia	-17.73 ***	2.44	-5.59 **	2.41	14.76 ***	0.72
9	Canada	-17.20 ***	1.65	-13.04 ***	1.16	5.02 ***	0.94
10	New Zealand	-11.37 ***	2.04	-3.08 *	1.57	9.35 ***	1.06
11	Japan	-31.84 ***	3.36	-26.23 ***	2.86	7.80 ***	1.47
12	Saudi Arab	-10.95 ***	1.93	-0.76	1.66	11.44 ***	1.74
13	Spain	-28.99 ***	2.06	-2.49	2.24	37.31 ***	2.77
14	Kuwait	13.60 ***	2.03	19.43 ***	1.21	5.13 ***	1.38
15	Lebanon	-10.40 ***	1.47	-6.14 ***	1.21	4.75 ***	1.08
16	Nepal	73.90 ***	4.02	67.35 ***	4.55	-3.77	2.21
17	Qatar	0.38	1.42	-2.12	2.09	-2.48 *	1.22
18	Thailand	-36.43 ***	3.28	-34.43 ***	6.05	3.14	4.37
19	France	-13.05 ***	1.65	-1.18	2.35	13.66 ***	1.25
20	China	-42.19 ***	1.84	-27.26 ***	2.41	25.83 ***	4.05
21	Other	-6.72 **	2.71	-11.30 ***	1.75	-4.91 ***	1.13
Total		-5.89***	1.09	-5.08***	1.04	0.86**	0.28

*Note: 1. ***, ** & * are significant at the 1%, 5% and 10% levels, respectively; others are non-significant*

2. CAGR – Compound Annual Growth Rate and SE – Standard Error. 3. MT = Metric tonnes

The United States of America illustrated a negative and significant growth rate in terms of quantity (-14.65%) and value (-2.91%) while showing a positive growth rate in terms of price (13.75%). In the United Kingdom, a negative growth rate in quantity (-22.02%) and value (-10.69%) was found, while a positive growth rate in price (14.54%) was observed, and similar results were also found by Patil (2022).

Table 2: Destination Pattern of export quantity of flowers from India (2013-14 to 2023-24)

No.	Country	Quantity (MT)	Value (Rs. Lacs)
1	U. S. A.	1193.12 (12.83%)	3094.01 (16.72%)
2	U. K.	940.12 (10.11%)	2582.41 (13.95%)
3	U. A. E.	816.03 (8.77%)	1666.09 (9.00%)
4	Malaysia	684.97 (7.36%)	1445.57 (7.81%)
5	Singapore	1598.16 (17.18%)	1432.86 (7.74%)
6	Germany	487.52 (5.24%)	1266.90 (6.84%)
7	Netherland	422.97 (4.55%)	968.30 (5.23%)
8	Australia	175.53 (1.89%)	651.15 (3.52%)
9	Canada	243.61 (2.62%)	529.45 (2.86%)
10	New Zealand	115.81 (1.24%)	496.18 (2.68%)
11	Japan	204.41 (2.20%)	437.40 (2.36%)
12	Saudi Arab	181.44 (1.95%)	377.74 (2.04%)
13	Spain	68.47 (0.74%)	317.67 (1.72%)
14	Kuwait	105.21 (1.13%)	270.29 (1.46%)
15	Lebanon	52.70 (0.57%)	204.22 (1.10%)
16	Nepal	444.37 (4.78%)	192.58 (1.04%)
17	Qatar	77.31 (0.83%)	170.45 (0.92%)
18	Thailand	56.94 (0.61%)	148.04 (0.80%)
19	France	62.30 (0.67%)	128.58 (0.69%)
20	China	63.39 (0.68%)	127.17 (0.69%)
21	Other	1308.15 (14.06%)	2002.19 (10.82%)
Total		9302.54 (100.00%)	18509.24 (100.00%)

Malaysia, Kuwait and Singapore also displayed strong CAGRs, indicating an increasing export trend over the study period. The trend in other countries in terms of quantity, value and price is -6.72%, -11.30% and -4.91%, respectively. Nepal has the highest growth rate in terms of quantity (73.90%) and value (67.35%), while in terms of price (37.31%), Spain was the leading one.

The results of the destination pattern of export of flowers from India revealed that Singapore was the highest importer of flowers in terms of quantity (17.18%), while in terms of value, the United Arab Emirates (16.72 %) topped the list, followed by the United Kingdom with a share (10.11%, 13.95%), United Arab Emirates (8.77%, 9%), and Malaysia (7.36%, 7.81%) in terms of quantity and value, respectively (shown in Table 2). On the other hand, the share of other countries was 14.06 per cent in terms of quantity, while in terms of export value, it was 10.82 per cent, which showcases the higher contribution of the top 20 countries than the others.

Conclusion

In sum, it reveals that the growth performance of flower exports from India remained negative and significant during the study period. While the markets like Nepal and Spain illustrated a higher growth rate while the countries like United Kingdom and United States of America shown negative trend even though it reserved the highest destination share. Due to this higher fluctuation and negative trend which emphasized a need for more strategic policy, better market access and strong trade agreements to improve our trade. It is a matter of concern for policy maker to implement such policies which just not only expand our exports but also sustain and diversified it such as floriculture markets that opens a new opportunity to generate a more income and provided a massive employment.

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Volume: 06 Issue No: 10

AGRICULTURAL EXTENSION MUST MOVE BEYOND DISSEMINATION

Article ID: AG-VO6-I10-99

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Introduction

Agricultural extension is often described as the bridge between agricultural research and farmers. The metaphor remains useful but incomplete. A bridge can carry a message from one side to another; it cannot ensure that the message is relevant, trusted, affordable or useful under the conditions in which a farmer must act. That distinction matters today. Farmers face changing weather, uncertain markets, new pests, rising input costs and an expanding stream of advice from public agencies, private companies, social media and fellow farmers. The central challenge is no longer simply how to disseminate more information. It is how to help farmers make better decisions.

My view is that agricultural extension must be judged less by the number of meetings conducted, leaflets distributed or messages sent and more by whether it improves farmers' capacity to understand options, assess risks and act with confidence. This is not an argument against technology transfer. Research-based technologies remain essential. It is an argument that technology transfer is only one part of a much larger responsibility.

The old model is no longer enough

Agricultural extension has evolved from largely top-down systems of technology dissemination towards approaches that are more participatory, decentralised and pluralistic. Public departments remain important, but universities, research institutions, farmer organisations, cooperatives, Non-Governmental Organisations (NGOs) and private advisory providers also influence agricultural decisions. The Food and Agriculture Organization of the United Nations recognises this wider shift in extension and advisory services.

Yet institutional change does not always translate into a change in everyday practice. Extension can still become a one-way exercise: experts decide what farmers need to know and then deliver standard messages to diverse communities. But a smallholder cultivating a rainfed plot, a farmer growing high-value vegetables and a producer linked to a commercial value chain do not necessarily need the same advice. Even farmers growing the same crop may face different soil conditions, water availability, labour constraints, market access and levels of risk.

An extension system that treats these differences as minor details will struggle to remain credible. Farmers do not reject advice simply because they are resistant to change. Sometimes the advice does not fit their resources, timing or local conditions. Sometimes the risks of adopting a recommendation fall entirely on the farmer while the benefits remain uncertain. Effective extension must begin by listening to these realities rather than assuming that information automatically produces adoption.

More information is not always better

Digital tools have widened the possibilities for agricultural communication. Mobile phones, messaging services, videos, online platforms and emerging artificial intelligence applications can help deliver information quickly and in local languages. These developments should be welcomed. They can complement field visits and make specialist knowledge accessible to people who might otherwise struggle to reach it.

However, access to information should not be confused with access to reliable advice. A farmer may receive conflicting recommendations about a pest, fertiliser, pesticide or crop variety from several sources in a single day. Online content may be incomplete, commercially motivated or unsuitable for the farmer's location. A digital platform can transmit a recommendation instantly, but it cannot guarantee that the recommendation is appropriate for a particular field.

The next stage of digital extension should therefore focus not on the number of messages sent but on the quality of decisions supported. Digital systems need credible sources, local relevance, transparent limitations and pathways through which farmers can seek clarification. They should also connect users to qualified extension personnel when a question requires diagnosis, field observation or professional judgement. Institutional coordination, service quality and the capacity of advisers remain important even as delivery models diversify.

Extension workers must become knowledge brokers

The future extension worker should not be seen merely as a messenger carrying recommendations from a research station to a village. The role should be closer to that of a knowledge broker: someone who helps farmers identify a problem, locate credible evidence, compare possible responses, understand trade-offs and connect with relevant institutions.

This requires more than digital literacy. Extension personnel need continuing opportunities to update their technical knowledge, interpret climate and market information, communicate uncertainty and facilitate farmer-led learning. They also need access to specialists across disciplines. A pest problem may require entomological expertise; a water shortage may call for hydrological advice; a marketing difficulty may require support in grading, storage, collective marketing or value-chain connections. No single extension worker can be an expert in everything, but a well-connected extension system can bring the right expertise to the farmer.

The same principle should guide the relationship between research and extension. Researchers need regular feedback on the problems farmers actually encounter. Extension personnel need channels to communicate field observations and farmers' assessments of new technologies. Farmers, in turn, should participate in identifying research priorities and evaluating whether proposed solutions work in practice. Without this two-way exchange, research may produce technically sound innovations that are difficult to use under real farming conditions.

Public extension still has a vital role

The growth of private and digital advisory services does not make public extension obsolete. Rather, it makes its public-interest role more important. Commercial providers can offer useful services, especially where there is a viable market. But advice related to climate risks, natural-resource conservation, safe pesticide use, water management and the needs of marginalised farmers cannot be left entirely to commercial incentives.

Public extension should help ensure that credible advice reaches farmers who have limited purchasing power or poor digital connectivity. It should also act as a trusted convenor, bringing research institutions, line departments, local governments, farmer producer organisations and community groups together. In a pluralistic system, the objective should not be to make every institution deliver everything. It should be to make the different providers work coherently, with clear responsibilities and accountability to farmers.

This is particularly important when agricultural decisions are linked to natural resources. Water availability, soil health, rainfall variability and crop choice are interdependent. Advice on crop production that ignores water availability can create new risks. Similarly, water-conservation interventions are unlikely to endure if farmers are not involved in planning, maintaining and evaluating them. Extension should therefore help farmers connect individual farm decisions with the wider landscape and community context.

Measure outcomes, not activity alone

Extension programmes often report activities that are easy to count: training sessions, participants, demonstrations, publications and digital messages. These indicators are useful for monitoring delivery, but they do not tell us whether farmers benefited. A programme may conduct many events without changing a decision or solving a problem. Another may reach fewer farmers but help them reduce losses, use water more efficiently or improve the quality of their produce.

Evaluation should therefore ask harder questions. Did farmers understand the advice? Could they afford to act on it? Was it relevant to local conditions? Did it reduce risk or improve livelihoods? Which groups benefited and which were left out? Were farmers able to question the recommendation and receive a response? These questions would help shift extension from an activity-driven culture towards a learning-oriented and accountable service.

A practical way forward

Four priorities deserve attention. First, make farmer demand and local diagnosis the starting point for advisory programmes rather than treating them as final steps after a technology has been selected. Second, combine digital delivery with human support so that technology extends the reach of competent advisers instead of being treated as a substitute for them. Third, strengthen coordination among public agencies, research institutions, farmer organisations and responsible private providers. Fourth, evaluate extension by changes in farmers' knowledge, decisions, resilience and livelihoods alongside conventional activity indicators.

These priorities do not require abandoning the achievements of traditional extension. Demonstrations, farmer meetings, field days and training remain valuable when they are responsive to real needs. What must change is the assumption that delivering a message is equivalent to solving a problem. Extension should be prepared to say when evidence is uncertain,

when a recommendation needs local validation and when a farmer's experience challenges an established assumption.

From technology transfer to trusted decision support

Agricultural extension will continue to evolve as farming becomes more connected to digital technologies, markets, climate information and resource-management systems. But its purpose should remain clear: to strengthen farmers' ability to make informed choices. The measure of progress should not be whether every farmer receives more messages. It should be whether farmers can identify trustworthy advice, understand their options and obtain timely support when decisions are difficult.

The future belongs neither to digital tools alone nor to conventional field extension working in isolation. It belongs to a connected, responsive and accountable advisory system in which technology, scientific expertise and farmers' own knowledge reinforce one another. Agricultural extension must move beyond dissemination. Its real task is to turn knowledge into decisions that farmers can trust.

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Volume: 06 Issue No: 10

WHEN PHARMACEUTICALS MEET CLIMATE CHANGE: THE HIDDEN THREAT TO MARINE LIFE

Article ID: AG-VO6-I10-100

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Abstract

Pharmaceutical pollution and climate change are emerging environmental challenges that may interact to influence marine ecosystem health. Pharmaceutical residues enter aquatic environments through wastewater discharges, sewage treatment effluents and other anthropogenic sources. Although these compounds are designed to produce specific biological effects in humans, their presence in aquatic ecosystems raises concerns about unintended effects on non-target organisms. Climate-related changes, particularly rising water temperatures and ocean acidification, may further modify contaminant behaviour and biological responses. Blue mussels (*Mytilus* spp.) are valuable organisms for investigating these interactions because of their filter-feeding behaviour and suitability for environmental monitoring. This article examines pharmaceutical contamination pathways, the ecological relevance of citalopram, the role of mussels as biological sentinels, and the importance of assessing multiple environmental stressors. Integrating chemical analysis with physiological, biochemical and molecular approaches can improve our understanding of contaminant effects and support climate-aware marine environmental risk assessment.

Keywords: Pharmaceutical pollution, citalopram, climate change, marine ecotoxicology, blue mussels, emerging contaminants, bioaccumulation, environmental risk assessment.

1. Introduction

The ocean supports extraordinary biodiversity and provides essential ecosystem services, including fisheries production, nutrient cycling, carbon storage and coastal protection. However, marine ecosystems are increasingly exposed to anthropogenic pressures, including chemical pollution and climate change. Among the emerging contaminants receiving growing scientific attention are pharmaceutical residues, which can enter aquatic environments following their use in human and veterinary medicine (Gaw *et al*., 2014; aus der Beek *et al*., 2016; Fabbri & Franzellitti, 2016).

Pharmaceuticals are biologically active substances designed to interact with specific physiological processes. Following administration, some parent compounds and their metabolites are excreted and transported through wastewater systems. Conventional wastewater treatment processes may not completely remove all pharmaceutical substances, allowing residues to reach rivers, estuaries and coastal waters (Kümmerer, 2009; OECD, 2019; O'Flynn *et al*., 2021).

Climate change introduces an additional dimension to this challenge. Increasing water temperatures and changes in seawater chemistry can affect marine physiology and modify contaminant behaviour. Consequently, understanding pharmaceutical pollution under changing climatic conditions is important for improving ecological risk assessment (Gunderson *et al*., 2016; Bethke *et al*., 2023).

"Medicines designed to heal humanity can become hidden challenges for marine life, especially when a warming ocean changes the way pollutants interact with living organisms."

2. Pharmaceutical Pollution: From Medicine to Marine Ecosystems

Pharmaceutical residues can enter the environment through several pathways, including human and veterinary excretion, wastewater treatment plant discharges, hospital effluents, pharmaceutical manufacturing and the improper disposal of unused medicines. Their relative contributions vary according to the compound, geographical location, patterns of use and effectiveness of wastewater management (Kümmerer, 2010; aus der Beek *et al*., 2016; O'Flynn *et al*., 2021).

Once released, pharmaceuticals may remain dissolved in water, associate with suspended particles or sediments, undergo chemical or biological transformation, or become available for uptake by aquatic organisms. Their environmental fate depends on properties such as solubility,

ionisation, chemical stability and affinity for biological tissues (Santos *et al*., 2010; Pereira *et al*., 2020).

Pharmaceutical residues have been reported in marine and coastal environments, although monitoring is less comprehensive than for several established pollutant groups. Dilution, complex coastal hydrodynamics and the presence of transformation products create additional analytical challenges (Gaw *et al*., 2014; Branchet *et al*., 2021).

The presence of a pharmaceutical does not automatically indicate ecological harm. Risk depends on environmental concentration, exposure duration, biological sensitivity and the potential for interactions with other stressors. Nevertheless, repeated exposure and the biological activity of these compounds make pharmaceutical contamination an important subject of environmental investigation (Santos *et al*., 2010; Fabbri & Franzellitti, 2016; Mezzelani & Regoli, 2022).

3. Citalopram: An Emerging Concern in Aquatic Ecotoxicology

Citalopram is a selective serotonin reuptake inhibitor (SSRI) prescribed for the treatment of depression. Its therapeutic action involves serotonin signalling in humans. However, biologically active pharmaceutical compounds released into aquatic environments may interact with physiological processes in non-target organisms, making their environmental effects an important research topic.

SSRI antidepressants have been investigated because of their occurrence in aquatic environments, potential uptake by organisms and capacity to produce biological responses in non-target species. Silva *et al*. (2015) reviewed evidence concerning the uptake, bioaccumulation and ecotoxicological effects of this pharmaceutical class.

A particularly relevant study published in the *Journal of Hazardous Materials* investigated the combined exposure of the marine mussel *Mytilus galloprovincialis* to polyethylene microplastics and two pharmaceuticals, citalopram and bezafibrate. The researchers examined pharmaceutical bioaccumulation and metabolic responses, demonstrating that contaminant accumulation and biological effects do not necessarily follow the same pattern (Castaño-Ortiz *et al*., 2023).

This distinction is important because measuring a contaminant concentration in tissue alone may not adequately explain its biological consequences. Metabolic investigations can

provide additional information about changes in energy production, cellular maintenance and other physiological processes.

More broadly, research on pharmaceutical contamination has identified potential effects on biochemical, cellular and physiological functions, although responses vary with the compound, organism, concentration and exposure duration (Fabbri & Franzellitti, 2016; Mezzelani & Regoli, 2022).

These findings support further investigation into the environmental behaviour and biological effects of citalopram, including the possible influence of temperature and other environmental conditions. Direct evidence for the combined effects of citalopram and climate warming in blue mussels remains an important area for further research.

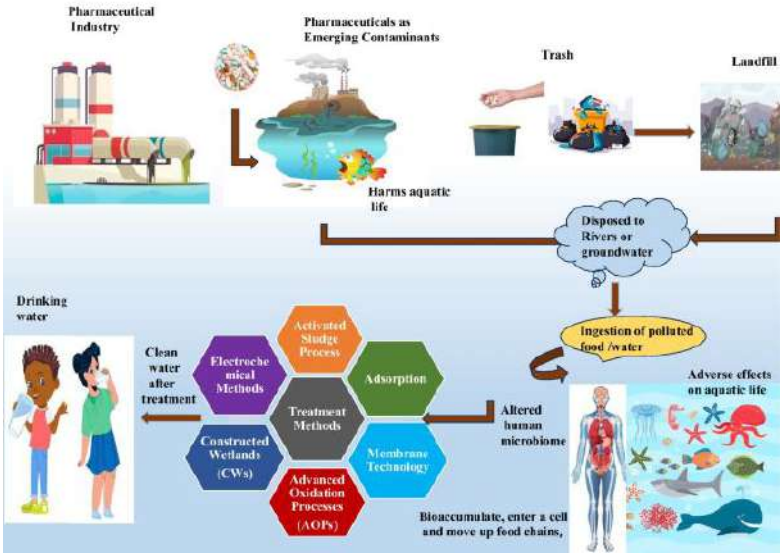


Figure 1. Pharmaceutical contaminants and their environmental impacts. Source: Bano *et al.* (2025), https://doi.org/10.1007/s11270-025-08181-x.

4. Blue Mussels: Sentinels of Marine Environmental Quality

Blue mussels and related species of the genus *Mytilus* are widely used in coastal pollution monitoring. Their ecological characteristics make them useful for examining contaminant exposure and biological responses in marine environments (Beyer *et al*., 2017).

As filter feeders, mussels process seawater to obtain food particles. During this process, they encounter substances present in the surrounding water, including certain chemical contaminants. Their relatively sedentary nature also allows researchers to investigate pollution associated with particular locations.

Mussels can be examined using several complementary approaches:

- **Chemical analysis:** Determines the concentrations of pharmaceutical residues and relevant metabolites in water and biological tissues.
- **Physiological measurements:** Investigates changes in respiration, filtration and energy-related processes.
- **Biochemical biomarkers:** Evaluates antioxidant responses, oxidative stress and other indicators of cellular disturbance.
- **Histological analysis:** Identifies structural changes in tissues.
- **Molecular and metabolic approaches:** Investigates changes in gene expression, proteins and metabolic pathways.

Beyer *et al*. (2017) highlighted the value of mussels as environmental sentinels while emphasising the need to account for confounding factors, including season, biological condition and differences among sampling locations.

Using several endpoints together is particularly valuable because chemical exposure, physiological responses and cellular effects represent different aspects of the same environmental problem. Integrated evidence can help researchers distinguish contaminant presence from its potential biological consequences.

5. Climate Change and the Changing Nature of Toxicity

Marine organisms are increasingly exposed to changing environmental conditions, including rising temperatures, ocean acidification and alterations in oxygen availability. Temperature is especially important because it influences metabolic activity, oxygen demand and physiological performance.

In ectothermic organisms such as mussels, warming can modify energy requirements and physiological functioning. When temperatures approach or exceed an organism's tolerance range, maintaining normal biological processes may become more demanding.

Temperature can also influence contaminant uptake, elimination and metabolism. Changes in physiological activity may alter the internal concentration of a substance or the organism's capacity to respond to chemical exposure. The direction and magnitude of these effects depend on the particular contaminant, species and environmental conditions (Gunderson *et al*., 2016; Bethke *et al*., 2023).

Bethke *et al*. (2023) reviewed research on warming, acidification and pharmaceutical toxicity in aquatic organisms. Their findings indicated that climate-related stressors can modify acute and chronic toxicity, bioaccumulation and sublethal biological responses. However, the responses were compound-dependent, and important research gaps remain.

Multiple stressors can also interact in different ways. Crain *et al*. (2008) demonstrated that interactions among human-induced stressors in marine systems can be additive, synergistic or antagonistic. Consequently, the combined effects of two stressors cannot always be predicted by simply adding their individual effects.

This uncertainty is scientifically significant. A pharmaceutical that produces a particular response under one temperature condition may produce a different response under warmer conditions. Warming may intensify some effects, reduce others or alter the biological response entirely.

For this reason, pharmaceutical toxicity studies conducted under only one environmental condition may not fully represent the circumstances experienced by marine organisms in a changing climate.

6. Looking Beyond Survival: Molecular and Metabolic Evidence

Traditional toxicity assessments often examine mortality, growth and reproduction. Although these remain important endpoints, they may not fully reveal the mechanisms responsible for biological disturbance.

Sublethal responses can provide early evidence of physiological stress. Changes in respiration, antioxidant defence, cellular integrity and metabolic activity may occur without immediate mortality. Their ecological significance must nevertheless be interpreted alongside exposure conditions and other biological evidence.

Metabolomics examines changes in small molecules involved in biological processes. It can help identify alterations in energy metabolism, cellular maintenance and other biochemical pathways. Transcriptomics investigates RNA expression, while proteomics examines changes in proteins. These complementary approaches can help connect contaminant exposure with biological responses.

The citalopram–microplastic–mussel investigation by Castaño-Ortiz *et al*. (2023) illustrates the value of metabolomic analysis in studying pharmaceutical exposure in marine bivalves.

The adverse outcome pathway framework provides another way of organising scientific evidence. It links an initial biological interaction with subsequent molecular, cellular and organism-level effects, potentially extending to outcomes relevant to populations and ecosystems (Ankley *et al*., 2010).

However, molecular changes should not automatically be interpreted as evidence of ecological damage. Their significance depends on the magnitude and persistence of the response and whether it can be linked to adverse effects at higher levels of biological organisation.

7. Towards Climate-Aware Marine Pollution Management

Addressing pharmaceutical pollution requires action at several levels. Improved wastewater treatment, responsible disposal of unused medicines, appropriate pharmaceutical manufacturing practices and better environmental monitoring can help reduce the release of pharmaceutical residues.

The OECD (2019) recommends a comprehensive approach to managing pharmaceutical residues, emphasising prevention, cooperation among stakeholders and improved understanding of environmental risks.

Monitoring programmes should also consider the characteristics of receiving environments. Branchet *et al*. (2021) identified the need for improved sampling strategies and more systematic monitoring of pharmaceuticals in marine water, sediments and biota.

Climate-aware ecotoxicological studies can complement these efforts by investigating how environmental changes modify contaminant effects. Experiments involving environmentally relevant concentrations, appropriate temperature treatments and multiple biological endpoints can help identify conditions under which marine organisms may be particularly vulnerable.

Such research should support evidence-based decisions rather than assume that every pharmaceutical presents the same level of risk. Chemical properties, exposure patterns, species sensitivity and environmental conditions must all be considered.

Conclusion

Pharmaceutical pollution represents an important challenge for marine environmental management, particularly when considered alongside climate change. Residues of biologically active compounds can reach coastal waters, while changing temperatures may modify contaminant uptake, metabolism and biological responses.

Citalopram provides a useful example of why emerging pharmaceutical contaminants deserve investigation. Studies involving mussels have demonstrated the value of combining bioaccumulation measurements with metabolic evidence to understand biological responses. Blue mussels, in turn, provide useful organisms for monitoring environmental exposure and investigating physiological and cellular effects.

Future research should integrate chemical measurements, physiological assessments and molecular approaches under environmentally relevant conditions. Such investigations can help clarify the interactions between pharmaceutical pollution and climate-related stressors, identify important knowledge gaps and strengthen marine ecological risk assessment.

Protecting marine ecosystems requires an understanding not only of which contaminants are present, but also of how they interact with living organisms and changing environmental conditions. Integrating pharmaceutical monitoring with climate-aware ecotoxicology is an important step towards that goal.

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Volume: 06 Issue No: 10

WOMEN ENTREPRENEUR: FROM BIKA VILLAGE TO THE GLOBAL MARKET

Article ID: AG-VO6-I10-101

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Age: 62

Village: Bika, (Nawanshahr)

Enterprise: Aatman udyog

Expertise: Chemical free bathing and laundry soaps

Experience: 16 years

From Bika Village to the Global Market: The Inspiring Journey of Rashpal Kaur

The narrative of rural empowerment in India is undergoing a profound transformation, driven by visionary leaders who combine global perspectives with grassroots realities. At the forefront of this movement is Rashpal Kaur, a 62-year-old entrepreneur who has spent the last 16 years rewriting the script for rural women's employment. Through her enterprise, **Aatman Udyog**, and her flagship brand, **Karmic**, Rashpal has successfully built a bridge connecting the small village of Bika in Nawanshahr, Punjab, to the highly competitive global market for organic, chemical-free personal care products.



The Call of the Roots: A Journey Back Home

For three decades, Rashpal Kaur lived a comfortable life in England, immersed in a different culture and standard of living. However, the connection to her homeland remained strong. The turning point came in 2010 during a conversation with an acquaintance, Archana Shah, who expressed a deep desire to initiate a meaningful, impactful project in India. This dialogue struck a chord with Rashpal. Rather than enjoying a quiet retirement abroad, she made the bold decision to return to her roots in Bika village.

Rashpal returned with a definitive mission: to leverage her international exposure, urban sensibilities, and passion for sustainability to uplift and benefit rural women. She recognized that true empowerment does not come from charity, but from equipping individuals with sustainable livelihoods and financial independence.

Merging International Training with Local Expertise

To turn her vision into a viable business, Rashpal combined cutting-edge international standards with local agricultural intelligence. While still in England, she underwent formal training specifically focused on the manufacturing of organic cosmetic products. She learned the precise science of formulation, shelf-life management, and European quality standards.

Upon her return to Punjab, she grounded this knowledge by collaborating with local institutions. She sought and received essential technical training and guidance from the **Krishi Vigyan Kendra (KVK) in Langroya**. This dual exposure allowed her to achieve several critical milestones:

- **Standardizing Quality Recipes:** She perfected the formulations for handmade bathing soaps, laundry soaps, and lip balms, ensuring consistency across production batches.
- **Strict Purity Standards:** The products were formulated to be entirely chemical-free, utilizing only natural oils, plant-based ingredients, and indigenous herbs.
- **Bridging the Gap:** She successfully merged traditional, manual rural labor with modern, rigorous organic standards, ensuring that a product made in a village kitchen could meet international consumer expectations.

The "Karmic" Philosophy and Strategic Leadership

Rashpal's leadership style goes far beyond traditional management; she has built a brand infrastructure anchored in deep ethical values. Under the umbrella of Aatman Udyog, she launched the brand name **Karmic**. The name was chosen deliberately to reflect the universal

concept of Karma—the belief that good, pure actions inevitably yield good results. This philosophy serves as the guiding light for the enterprise's NGO-driven workforce, prioritizing purity, environmental consciousness, and ethical production above simple profit margins.

Understanding the market was another area where Rashpal's leadership shone. She quickly recognized that the purchasing power and demand for high-end organic products were limited within rural markets. Instead of scaling down her quality, she pivoted her market strategy toward premium, artisanal platforms.

She secured a coveted stall at **Dilli Haat** in New Delhi, a renowned hub for traditional Indian crafts and handlooms. This move was a masterstroke. Not only did it expose the brand to affluent, health-conscious urban consumers and international tourists, but it also served as a powerful proof of concept for the village women back in Bika. Seeing their handmade products appreciated on a national stage injected an immense sense of pride and confidence into the local workforce.

Navigating Regulatory Barriers and Scaling Globally

The journey from a local village initiative to an export-ready business was fraught with bureaucratic challenges. In India, obtaining manufacturing licenses for cosmetic and personal care products involves navigating stringent, complex regulatory frameworks—a task that frequently deters rural NGOs.

"Resilience is not just about enduring challenges; it is about finding the right partners and paths to overcome them."

With unwavering resilience and the vital support of local associates like Rashpal systematically tackled the legal and bureaucratic hurdles. They successfully transitioned the organization from a modest, decentralized village setup into a fully compliant, licensed corporate entity capable of fulfilling international export requirements.

A Model for Sustainable Rural Development

Today, Rashpal Kaur stands as a beacon of hope and a model for sustainable, organic entrepreneurship in rural Punjab. Over 16 years of dedicated effort, Aatman Udyog has proven that rural women can produce world-class goods when given the right training, infrastructure, and leadership.

By utilizing local resources and creating a premium market for chemical-free products, Rashpal has not only preserved the environment but has also infused the rural economy of

Nawanshahr with a sustainable source of revenue. Her story is a powerful testament to the fact that with vision, tenacity, and a commitment to quality, a small village can resonate across the global marketplace.

Volume: 06 Issue No: 10

'KHET BACHAO (RABI)' 2026: HEALTHY SOIL, PROSPEROUS FARMERS'

Article ID: AG-VO6-I10-102

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Introduction

The Ministry of Agriculture and Farmers Welfare, Government of India has been giving top priority to agriculture sector and it is manifested through various coordinated efforts involving agricultural universities, state departments of agriculture and allied sectors. These coordinated efforts run in the form of regular seasonal campaigns aimed at promoting sustainability, profitability and empowerment of farming communities. After the *Khet Bachao Abhiyan* of *Kharif* 2025, MoA &FW has now launched the 40 days long nationwide *Khet Bachao Abhiyan (Rabi)* in the country which will be implemented w. e. f Oct. 22 to Nov. 30.The focus of the campaign will be on capacity building of farmers, farm women and youths, awareness and promotion of sustainable practices like soil health management, crop residue management, balanced fertilizer use, integrated management of crops, nutrients and diseases, scientific production of pulses and oilseeds, natural farming, Climate resilient practices. Besides awareness of different government schemes, trade agreements, importance of generating unique Id for farmers under Agri stack is also an important aspect of the campaign.

The campaign will simultaneously focus on water conservation though promotion of initiatives like per drop more crop, crop diversification, promotion of pulses and oilseeds in rice fallows and location specific contingency measures to neutralize the adverse effects of climatic uncertainties. All these issues will be a nationwide priority to be undertaken through this nationwide movement aimed at restoring health of soils for saving our farms and securing the farming community.

Khet Bachao Rabi 2026 *Abhiyan*

While announcing the launch of the nationwide campaign, Union Minister of Agriculture

and Farmers Welfare, Sh. Shiv Raj Singh Chauhan told that the *Khet Bachao Rabi* 2026 *Abhiyan* intends to promote sustainable farming, protect soil health, and empower farmers. The Abhiyan will specially focus on balanced fertilizer use, reducing overdependence on synthetic/chemical fertilizers and promoting soil test-based nutrient management including green manure and bio-fertilizers. It will focus on farmers' outreach, awareness of the farmers regarding different welfare schemes, various nationwide missions like National mission on pulses/oilseeds, National Mission on Food Processing, National Mission on Natural Farming, helping farmers easily access and enroll in government programs like the Kisan Credit Card (KCC), PM-Kisan, weather based agro-advisories, distribution of farm machinery under different schemes and '*Khet Bachao'* Abhiyan will also serve to check whether the inputs like fertilizers, seeds, pesticides etc available at various input shops especially in rural areas are providing quality inputs to farming community.

Union Minister campaign

Union Minister while chairing the high level preparatory meeting emphasized that the campaign will go beyond mere awareness and focus on practical, on-ground support for farmers. The '*Khet Bachao'* Abhiyan will run throughout the country with a coordinated action plan. Krishi Vigyan Kendras have to closely coordinate with the state departments of agriculture and should avoid duplication of efforts. Special focus will be on exclusively assigned to 100 districts having a very high chemical fertilizer consumption rate.

Balanced Use of Fertilizers

Owing to the indiscriminate use of chemical fertilizers that has already resulted in degradation and pollution of our natural resources, the government has already concluded a nation-wide campaign on 'Balanced Use of Fertilizers'. Fertilizers are a critical input in the agricultural production process. India is the world's second largest consumer and third largest producer of fertilizers with usage roughly reaching 199.1 kg per hectare by 2023. During 2025-26, India total assessed fertilizer requirement reached 677.18 lakh Metric Tonnes which is a roughly 4% increase compared to 649.43 LMT in 2024-2025. On a per hectare basis, Punjab is the highest consumer of fertilizers in India with consumption often exceeding 190-247 kg/ha due to intensive rice-wheat cropping. While Uttar Pradesh leads in absolute total consumption, Punjab, along with Haryana and Andhra Pradesh, has the highest usage per unit area, significantly exceeding the national average. Of the top 100 fertilizer consuming district in the

country, Uttar Pradesh leads with 30 of the 100 top fertilizer consuming districts. Of the remaining districts in different states, Andhra Pradesh has 08, Bihar has 02, Chhattisgarh has 01, Gujarat has 08, Haryana has 07, Karnataka has 05, Madhya Pradesh has 11, Maharashtra has 02, Odisha has 01, Punjab has 11, Rajasthan has 10 and West Bengal has 04.

Indiscriminate use of fertilizers

The continuous and indiscriminate use of fertilizers from the last so many decades have led to many environmental, social and health issues. Chemical fertilizers cause significant environmental and health problems, including water contamination (Eutrophication), soil degradation (acidification), biodiversity loss, and greenhouse gas emissions (nitrous oxide). Excessive use leads to nutrient runoff, damaging aquatic ecosystems, and causes fertilizer burn, which dehydrates crops. Nutrient runoff (nitrogen, phosphorus) enters water bodies, causing algal blooms, killing aquatic life, and contaminating groundwater sources for decades. Overuse reduces organic matter, destroys soil microorganisms, and causes soil acidification and hardening, limiting long-term soil fertility.

Chemical fertilizers

Chemical fertilizers are a significant source of nitrous oxide (a greenhouse gas) and cause air pollution. Various gases released by chemical fertilizers lead to global warming resulting in increased temperature of the planet. The global warming further adversely affects the agricultural productivity particularly in the rainfed regions. Besides, continuous exposure to chemical runoff has been associated with cancer, including gastric and testicular cancer due to high nitrate levels. Plants grown with excessive chemical fertilizer often lack nutrient quality, despite rapid growth. The 'Balanced Use of Fertilizers' campaign focused on 4Rs *i. e* Purchasing Fertilizers from a Right source, applying them to different crops at Right rate *i. e* dosage per hectare, at Right time and at Right place. With Balanced Use of fertilizers, the initiative also promoted soil test based recommendations, Integrated Nutrient Management (INM), Organic and Natural Farming. The balanced use of fertilizers initiative aimed to reverse the declining soil health caused by imbalanced nitrogen (N), phosphorus (P) and potassium (K) ratios, which are heavily skewed towards nitrogen and to promote sustainable soil health and crop management practices.

Khet Bachao' Rabi campaign

Now, the more than a month long *'Khet Bachao' Rabi* campaign will give an opportunity to make farmers' aware of the scientific cultivation of different *Rabi* season crops. They will also

trained on the method of taking soil samples so that they can themselves take soil sample from their fields and send it for nutrient analysis in labs through concerned department and get their Soil Health Cards. Based on the results of soil test farmers will be asked to apply the fertilizers in their fields. Government has already implemented the National Mission on Natural Farming (NMNF) which is based on various microbial formulations like *Jeevamrita, Beejamrita, Neemastra, Agniastra* and others prepared from indigenous cow and other local resources available within the communities. Farmers will be encouraged to shift towards Natural farming for sustainability and remunerativeness. Farm women are also a crucial part of food grains production in the country but their contribution has seldom been recognized. They will also be a prime target of the Abhiyaan wherein they will be made aware of various schemes related to farm women.

Conclusion

There are many schemes of the government, but these schemes are yet to reach the farmers. It will be a good time to ensure that the deserving and needy farmers are facilitated to get themselves registered under different schemes so as to get their benefits. Already, Pre Rabi Campaign 2026 is going on in the UT of Jammu and Kashmir. ICAR institutes, Agricultural universities and Krishi Vigyan Kendras in respective districts will act as knowledge partners As knowledge partners, all the Krishi Vigyan Kendras of Sher-e-Kashmir University of Agriculture Sciences and Technology of Jammu under the leadership of Prof. B. N. Tripathi Hon'ble Vice Chancellor and Prof. Amrish Vaid, Director Extension are once again on the toes and amongst the farming communities in making this outreach initiative a truly practical one.

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Volume: 06 Issue No: 10

ONE FARM, MANY ENTERPRISES: HOW INTEGRATED FARMING CAN TRANSFORM INDIAN AGRICULTURE

Article ID: AG-VO6-I10-103

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Introduction

Integrated Farming System (IFS) is a farming approach that combines two or more complementary agricultural enterprises, such as crop production, dairy, poultry, fisheries, horticulture and vermicomposting, on the same farm to improve resource-use efficiency, recycle farm wastes, diversify production and enhance farmers' income and livelihood sustainability.

Farming is more than growing crops; it is about making the best use of every resource available on the farm. Today, farmers face several challenges, including rising cultivation costs, uncertain weather and fluctuating market prices. Depending on a single crop for income can make farming more difficult and risky. Integrated Farming System (IFS) offers a way forward by bringing together complementary enterprises such as crops, dairy, poultry, fisheries, horticulture and vermicomposting on the same farm. By connecting these activities, farmers can recycle farm wastes, use resources more efficiently, produce a variety of food products and create additional income opportunities. By combining crops, livestock, fisheries and recycling of farm resources, Integrated Farming System offers a practical pathway towards more resilient and sustainable farm livelihoods.

A Farm That Never Sleeps

Imagine a farmer standing in his paddy field early in the morning. The rice crop is growing well, but the expenses keep increasing. Fertilizers, pesticides, labour, electricity and irrigation consume a significant share of his earnings. A good harvest may bring a reasonable income, but an unexpected drought, flood, pest outbreak or fall in market prices can turn the entire season into a financial struggle.

Now imagine the same farmer walking a few steps beyond his paddy field. There is a small pond stocked with fish, a few dairy animals in a shed, poultry scratching in a protected enclosure, banana plants along the field bunds and a vermicompost unit converting organic wastes into valuable manure. Crop residues have a purpose, animal manure returns nutrients to the soil, and several farm enterprises contribute to the family's livelihood.

This is the idea behind the Integrated Farming System (IFS): a farm where different enterprises work together rather than operate as isolated activities.



The example is illustrative, but the principle is well established in agricultural research. IFS is an approach that combines two or more complementary agricultural enterprises to improve resource-use efficiency, diversify production and strengthen farm livelihoods. For Indian farmers, especially those managing small holdings, it offers an opportunity to make better use of the land, water, labour and other resources already available.

Beyond the Single-Crop Approach

Agriculture has traditionally focused on producing crops from the land. Crop cultivation remains essential, but relying on a single crop or a single source of income can expose farm families to substantial risks.

A crop failure may affect the entire year's earnings. Income from seasonal crops may also be irregular, while household expenses continue throughout the year. At the same time, crop residues, livestock manure and other biodegradable materials may remain underutilised.

Integrated Farming System addresses these challenges by viewing the farm as a connected unit. Crop production can be combined with dairy, poultry, fisheries, horticulture, fodder cultivation, beekeeping, mushroom production and vermicomposting, depending on the farmer's circumstances.

The objective is not simply to increase the number of enterprises. It is to establish useful relationships among them. For instance, crops provide grain, straw and fodder. Livestock supplies milk and manure. Crop residues and suitable organic wastes can be converted into compost. Horticultural crops provide fruits and vegetables, while a fish pond can contribute food and income where water availability and local conditions permit.

When these activities complement one another, the farm can produce a wider range of goods, use resources more efficiently and reduce dependence on a single enterprise.

The Strength of Integration: Turning Waste into Wealth

One of the most important principles of IFS is resource recycling. Consider a dairy unit. The manure produced by cattle can be collected and composted before being applied to suitable fields. This returns nutrients and organic matter to the soil and can reduce the need for some purchased fertilizers, depending on the manure's nutrient content and the crop's requirements.

Similarly, crop residues can be used as livestock feed when they are suitable and safe, incorporated into the soil, or composted. Residues that are diseased, contaminated or unsuitable for feeding require appropriate management.

Vermicomposting offers another opportunity. Earthworms process suitable biodegradable materials into vermicompost, which can be used as a soil amendment and nutrient source. Poultry litter and livestock manure can also contribute to compost production when managed correctly. The result is a more circular farming system in which materials that might otherwise be discarded become useful resources.



However, recycling must be scientifically managed. Fresh manure should not be applied indiscriminately, and untreated animal waste should never be introduced into fish ponds without appropriate technical guidance. Excess nutrients can contaminate water, create oxygen depletion and harm aquatic organisms. Composting, safe handling and suitable application rates

are essential. IFS does not eliminate the need for fertilizers, feed, energy or other external inputs. Rather, it aims to make better use of available resources while applying external inputs judiciously.

A Wetland Farm: Bringing Rice, Fish, Dairy and Poultry Together

Wetland agriculture provides an interesting setting for IFS, particularly in rice-growing regions of India. Rice can remain the principal enterprise, supported by complementary activities such as dairy, poultry, fisheries, horticulture and vermicomposting. Their combination depends on the size and layout of the farm, water availability, soil conditions, investment capacity and the farmer's management skills.

In a representative wetland model, rice and other suitable crops provide the main agricultural output. Banana and vegetables can diversify production in appropriate areas. Dairy animals provide milk and manure, while poultry offers eggs or meat according to the enterprise selected. A fish pond adds another source of food and income where water resources and pond conditions are suitable.

Boundary spaces can be used for selected fodder crops, fruit plants and other useful vegetation, provided they do not interfere with field operations, sunlight or irrigation.



The connections among these components are what make the system valuable. Manure can be processed into compost, crop by-products can be used where appropriate, and farm-produced fodder can support livestock. The farm may supply several products to the household and local market instead of depending entirely on one harvest.

Yet integration does not mean placing every possible enterprise on every farm. A wetland farm with limited water storage, for example, may not be suited to a large fishery unit. A farmer with insufficient fodder or labour may find dairy farming difficult to manage. Scientific planning must come before enterprise expansion.

More Than Income: Food, Nutrition and Employment

The benefits of IFS extend beyond financial returns. A diversified farm can provide cereals, pulses, milk, eggs, fish, fruits and vegetables, depending on the enterprises adopted. This variety can improve the availability of nutritious food for the farm family and reduce exclusive dependence on purchased food.

Different enterprises may also generate income at different times. Milk can be marketed regularly, vegetables may provide frequent sales, and field crops may generate seasonal returns. Fish, poultry and horticultural products can contribute at intervals suited to their production cycles. This distribution of production and income may help households manage expenses more effectively. It can also create work throughout the year for family members and farm workers, although the actual employment benefit depends on the scale and labour requirements of each enterprise. Women can play important roles in livestock care, poultry management, seed preparation, food processing, composting and the marketing of farm products. With appropriate training, access to finance and participation in decision-making, IFS can create opportunities for women to strengthen their economic contribution.

Building Resilience in an Uncertain Climate

Indian agriculture increasingly needs strategies that can cope with variable rainfall, heat stress, water scarcity and other production risks. Diversification can help spread some of these risks. If one crop performs poorly, another enterprise may still generate output or income. However, this protection is not absolute: a severe flood, drought, disease outbreak or market disruption may affect several components simultaneously.

IFS can also contribute to better natural-resource management. Recycling organic materials can return nutrients to the soil, while appropriate crop rotations, legumes, cover crops and residue management can support soil health. Rainwater harvesting, efficient irrigation and suitable fodder planning can improve the use of available water. Agroforestry and boundary plantations may provide additional products, shade or other ecological benefits where appropriately designed. Livestock manure can support nutrient cycling, although emissions from animals and manure management must also be considered.

Therefore, an environmentally sound IFS should not be judged merely by the number of enterprises it contains. Its performance should be assessed through measurable outcomes such as net income, water productivity, nutrient recycling, soil health, employment generation and

environmental impacts.

Start Small, Plan Scientifically

For farmers interested in adopting IFS, the first step is to assess existing resources rather than invest immediately in several new enterprises.

- ✓ Map the farm. Identify the available land, water sources, soil characteristics, existing crops, livestock, labour and infrastructure.
- ✓ Select compatible enterprises. Choose components that match local agroclimatic conditions, household skills, available investment and market demand.
- ✓ Plan the resource linkages. Identify how crop residues, manure, fodder, compost and water will be managed safely and efficiently.
- ✓ Calculate costs and expected returns. Include establishment costs, recurring inputs, labour, transport, animal health care, depreciation and possible production losses. Evaluate net returns rather than relying only on gross income.
- ✓ Seek technical guidance. Agricultural universities, Krishi Vigyan Kendras and agricultural extension departments can help farmers select suitable crops, livestock breeds, fish species and management practices.
- ✓ Expand gradually. Begin with manageable enterprises, maintain records and assess performance before introducing additional components.

Farmers should also examine the availability of reliable buyers, storage, transport, veterinary services and credit. A productive enterprise may still be unprofitable if market access is poor or operating costs are too high. Above all, an IFS model must be tailored to the farm. A rainfed farm, a wetland farm and a peri-urban farm will not necessarily benefit from the same combination of enterprises.

The Road Ahead: From Individual Enterprises to Integrated Thinking

The future of IFS depends not only on farmers but also on research institutions, extension workers, financial agencies and market systems.

Research should develop location-specific models and assess their long-term economic, environmental and social performance. Demonstration farms can help farmers understand the practical connections among enterprises. Training should cover resource recycling, livestock health, water management, record-keeping, marketing and safe waste handling.

Access to affordable credit, insurance, quality inputs and organised markets can make adoption easier. Farmer groups and cooperatives may also help smallholders purchase inputs, share equipment, process products and negotiate better market access. Digital tools can support farm planning, weather-based decisions, enterprise budgeting and market information. Nevertheless, technology must be accessible and relevant to farmers' needs. IFS should not be promoted as a universal solution or as a promise of instant prosperity. It requires planning, technical knowledge, labour and regular monitoring. Poorly chosen enterprises or unsafe waste-management practices can increase costs and create new problems. Its greatest strength lies in the thoughtful coordination of activities that suit a particular farm and family.

Conclusion: A Farm Is an Ecosystem of Opportunities

A Farmer's paddy field is important, but it is no longer expected to support the entire farm economy on its own. A carefully managed combination of crops, livestock, poultry, fisheries and resource-recycling activities may offer additional products, employment and income opportunities.

The transformation begins with a change in perspective: seeing the farm not as a collection of separate activities, but as a connected system in which each suitable enterprise can support another. For India's small and marginal farmers, this way of thinking offers a practical route towards more diversified production, better resource use and potentially more resilient livelihoods.

Sustainable agriculture is not only about producing more from the land; it is also about making better use of every resource the farm can responsibly provide.

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Volume: 06 Issue No: 10

EMPLOYMENT GENERATION THROUGH VEGETABLE NURSERY

Article ID: AG-VO6-I10-104

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Introduction

Nursery management involves overseeing the cultivation, care, and production of high-quality seedlings in a controlled environment. Key practices include ensuring adequate sunlight, using well-drained, nutrient-rich soil, proper irrigation (often via mist or drip), pest/disease control, and hardening off seedlings before transplantation. It aims to reduce seedling mortality, maximize growth, and ensure efficient, healthy plant production. Keeping in view this scenario KVK Dahigaon-ne (AhmednagarII) has decided to conduct the 5 Days training programme on Nursery Management and also under ASCI (Agriculture Skill Council of India). A 25 day's training programme of "Nursery Worker" was conducted in year 2018-19 and 2019-20 in which 40 rural youths participated. In this 25 days training programme nursery establishment, management, work responsibilities and marketing topics were covered same time practical sessions like vegetable seedling production, grafting, budding, layering, media -preparation, media sterilization etc. was conducted by KVK scientists. Mean time participants visits to different nurseries also arranged, to get the practical exposure over nursery management and marketing.

After the training, a participant name Mr. Abhishek Takawane from village Dighi, Tal-Newasa. He erected Shade net house over 5000 sq. ft. in 2023-24 for production of quality Vegetable seedlings on a commercial basis in protected conditions under close supervision of KVK Scientist. After good response he extended propagation house in the form of 10000 sq. ft. shade net. Mr. Abhishek Takawane named his nursery "Takawane Patil Hi-tech Nursery".

Number of Vegetable seedlings produced and sold by them in the financial year 2025.

Name of Crop	Number of Seedling sold	Rate per seedlings (Rs.)	Gross Income (Rs.)	Net Income (Rs.)
Cabbage	160000	0.90	144000.00	43200.00
Cauliflower	120000	1.00	120000.00	36000.00
Watermelon	110000	2.50	275000.00	82500.00
Muskmelon	80000	2.50	200000.00	60000.00
Chilli	170000	1.20	204000.00	61200.00
Brinjal	120000	1.00	120000.00	36000.00
Tomato	90000	1.40	126000.00	37800.00
Bitter Gourd	60000	4.00	240000.00	72000.00
Total	**910000**		**1429000.00**	**428700.00**









He sold 9,10,000 vegetable seedlings in nearby villages by mouth publicity. After gaining this experience, he expanded his nursery over an area of 15000 sq.ft. He formed the Whats App group of Vegetable growing farmers to advertisement of grown seedlings. He installed printed flex boards at nearby villages also used printed stickers at Krishi Seva Kendra, Gram Panchayat. Within short time span "Takawane Patil Hi-tech Nursery" became popular among the farmers due to quality seedlings and good service at doorstep of farmer. In year 2025 his gross income is Rs. 14,29,000.00 and net profit is Rs. 4,28,700.00. In future, he wishes to install poly house for raising of quality seedlings.

Volume: 06 Issue No: 10

NATURAL FARMING ENCOURAGES SELF-RELIANCE TO THE WOMEN FARMER

Article ID: AG-VO6-I10-105

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Introduction

Name of farmer: Mrs Kalyani Kailash Murdare

Address: Village +Post Bhagur Taluka Shevgaon Distt. Ahilyanagar M.S. Pincode: 414502

Mobile Number:9405004917

Age: 39 years

Education: B.A.

Size of land holding (in acre): 19 Acre

Area under Natural Farming: 19 Acres

Year of adoption of Natural Farming: 2020



Brief journey of women farmers to go for natural farming : Mrs Kalyani Murdare was living in Pune with her family and enjoying her life but she was upset by eating traditionally grown fruit and vegetables grown by adopting chemical farming. One day she decided to shift in the village to grow natural produce accordingly she purchased 19 acres undulated land in the

village to cultivate it since the year 2020. Now she was in search of an institute who can provide technical know how on natural farming. In this way, she came in contact with the Shri Marutrao Ghule Patil Shikshan Sanstha Krishi Vigyan Kendra, Ahilyanagar II scientists through a training programme during the year 2022 organized under Dr. Panjabrao Deshmukh Natural Farming Mission an initiative of Govt. Of Maharashtra to promote natural/organic farming among the farmers. This was real beginning of her journey towards natural farming.

Major Natural farming practices adopted :

KVK imparted training to her and motivated for adopting natural farming, resource conservation technique of sowing which includes adoption of broad bed and furrow, dry seeding as per requirement of the crops.In pursuance of this she is making use of every square feet of land by adopting multi cropping and multi storied cropping system crops and enterprise diversification includes field crops-green gram, black gram, red gram, wheat, sorghum, bengal gram, sugarcane etc horticultural crop varies from vegetable tomato, brinjal, coconut, mango, papaya, custard apple and agri allied activities includes dairy, goatery, poultry etc are practiced on her farm. Besides that mulching is followed by her in almost all the crops to maintain soil moisture, she has sown and planted on her farm. She is storing rain water in farm pond & well which has constructed on her field. Besides this she is also adopting micro irrigation to harvest maximum on the concept of slogan given by Honble Prime Minister Govt. Of India i.e. **"Per drop More crop" .** Nutritional kitchen garden is also maintained to supply house hold need of the vegetables of the family.

Bio-input Preparation and use (BRC, available) :

She is preparing beejmrut, jeevamrut, ghanjeevamrut, dashparni, gokripa amritam, neemastra, agniastra, brahmashtra, vermicompost, vermiwash, gomutra, sonthastra, tak based concoctions and bio pesticides, slurry preparation in tank etc are used by her at the farm to supply nutrients for crop growth and protect the crop from infestation of various insects and disease in natural farming.

Economic benefits:

At present women farmer is getting economical benefits from seasonal crop viz. Sugarcane, vegetable, cereals and pulse crop. Fruit crops are not in peak period right now and livestock component except indigenous Giri cow , goatery and poultry she has recently introduced in her farm. The economic details of **"Mrud Gandh"** farm are given as follows:

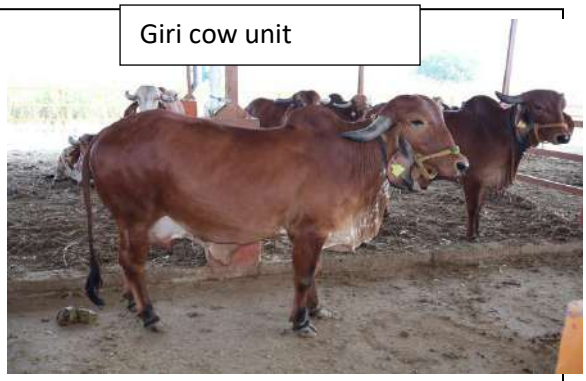
Table 1:Economic details of "Mrud gandh" Farm

S.No.	Crop/Enterprises	Area (Acre)/No.	Production Q/L/No.	Expenditure (Rs.)	Gross Income (Rs)	Net Income (Rs.)	B:C
Cereals							
01.	Sorghum, wheat	5	54	117000	360000	243000	3.07
Pulses							
02	Red gram, Black gram, green gram, bengal gram	5.5	19.5	67680	280020	212340	4.13
Sugarcrops							
03	Sugarcane	1	150	112000	578000	466000	5.16
Horticultural Crops							
04	Vegetable-Tomat, brinjal	0.75	60	80000	210000	130000	2.63
05	Fruit crops-Coconut, mango, jamun	610	11720	107860	273000	165140	2.53
Livestock Component							
06	Indegenous cow, goat and poultry	75	7500	535000	1275000	740000	2.38
	Total			**1019540**	**2976020**	**1956140**	**2.92**

Marketing of produces: KVK has got certified her farm under National Mission on Natural Farming (NMNF) project which give authenticity of her produce under PGS Certification programme. Farm produce are collected, graded, packaged and labeled in the brand name of **"Mrud Gandh".** She used to be contact of various societies situated in Pune and Mumbai

through social media platform from where she is getting order for buying her products on regular basis.

Giri cow unit



Cow dung product



Giri cow unit



Giri cow unit



Jeevamrut unit

Lessons learnt: Adoption of diversified crop and enterprise approach ensured her financial security all round the year and live in the society with self respect. Production of farm inputs at her own farm which are required to be applied in various crops minimize her cost of production substantially and also dependence on external inputs purchasing by adopting natural farming practices. Soil organic carbon enrichment gave strength to combat with biotic and abiotic stress management persisted during this year. A very pleasant feeling is observed by visitors coming to visit her farm.

Volume: 06 Issue No: 10

FROM FODDER TO FEED SECURITY: THE POWER OF GREEN FODDER MANAGEMENT IN INTEGRATED FARMING SYSTEMS

Article ID: AG-VO6-I10-106

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Introduction

Feed and fodder account for a major share of livestock production costs. Seasonal shortages of green fodder, inadequate protein supply and dependence on purchased feed can reduce the profitability of dairy farming. For small and marginal farmers, cultivating fodder within the farm and using available resources efficiently can help address these challenges.

Integrated Farming System offers an opportunity to connect fodder cultivation with crop production, livestock rearing, farm-boundary plantations and organic resource recycling. By growing suitable fodder grasses, protein-rich legumes and useful fodder trees, farmers can develop a more diverse feed supply while making productive use of land that might otherwise remain underutilised.

Early in the morning, a dairy farmer begins the day's routine by collecting green fodder for his cattle. He cuts Cumbu Napier grass, gathers a few leafy branches from the farm boundary and mixes the fodder before feeding the animals. Nearby, a small Azolla unit floats with fresh green biomass, while crop residues are stored for use during periods of fodder scarcity. It illustrates an important principle of Integrated Farming System (IFS): successful dairy farming begins not only with good cattle, but also with a dependable supply of nutritious feed.

The objective is not simply to produce more fodder. It is to produce the right combination of nutrients throughout the year.

Why Fodder Management Matters in IFS

A balanced cattle ration generally includes green fodder, dry roughage, concentrates, minerals and clean drinking water in quantities appropriate to the animal's body weight, milk production, stage of lactation and physiological condition.

Green fodder supplies moisture, fibre and nutrients. Leguminous fodders provide valuable protein. Dry fodder contributes essential roughage, while concentrate mixtures supply additional energy and protein when required.

No single fodder crop can meet all the nutritional requirements of every animal. For example, Cumbu Napier, is a productive source of green biomass, but its protein concentration may be insufficient for high-producing dairy cows when fed alone. Combining it with suitable leguminous fodders can improve the overall quality of the ration.

The integration of fodder production with existing farming activities also helps farmers manage resources more efficiently. Crop residues can provide roughage, selected legumes can be grown between suitable crop rows, fodder trees can occupy farm boundaries, and suitable organic materials can be composted for use in crop production.

Crop–livestock integrated farming systems has demonstrated the value of combining Bajra Napier, Desmanthus and fodder trees to support livestock feeding and resource recycling. The precise combination must be adapted to local soil, climate, water availability and farm requirements

Cumbu Napier: The Backbone of Green Fodder Production

Cumbu Napier, also known as Bajra Napier hybrid, is a perennial fodder grass developed by crossing pearl millet with Napier grass. Its vigorous growth, repeated harvesting potential and high biomass production make it a valuable fodder crop for dairy farms with adequate irrigation. Improved hybrids such as CO (BN) 4 and CO (BN) 5 are cultivated in Tamil Nadu. Under suitable management, Cumbu Napier can supply green fodder for much of the year.





Nutritional value and feeding

Cumbu Napier contains approximately 8–11% crude protein on a dry-matter basis in commonly reported descriptions, although its actual nutrient composition varies with cultivar,

maturity and management. Its high green biomass production makes it an important source of roughage for cattle.

Harvesting at an appropriate stage helps maintain palatability and digestibility. If the grass becomes excessively mature, the stems may become coarse and the fibre less digestible. Chopping the harvested fodder into suitable lengths can reduce wastage and help animals consume it more efficiently.

However, Cumbu Napier should not be the only component of a dairy ration. It should be supplemented with leguminous fodder, dry roughage and other nutrients according to the animal's requirements.

Desmanthus: A Protein-Rich Partner for Grass Fodder

Desmanthus (Desmanthusvirgatus), locally known as Velimasal or hedge lucerne, is a perennial leguminous fodder crop. Its importance lies in its ability to complement grass fodder with additional protein.

While Cumbu Napier provides abundant green biomass, Desmanthus can improve the nutritional balance of the ration. Growing both crops together is therefore a practical example of integration within the fodder production system.





Nutritional value and use

Desmanthus CO 1 is reported to contain approximately 20–22% crude protein on a dry-matter basis. It can be cut and fed fresh, either separately or mixed with grass fodder.

Its role is particularly important when farmers want to improve the protein supply without depending entirely on purchased protein-rich feed ingredients. As a legume, Desmanthus can also contribute to soil nitrogen cycling through its association with nitrogen-fixing bacteria, although the actual benefit depends on nodulation, soil conditions and crop management.

A combination of Cumbu Napier and Desmanthus creates a practical foundation for a home-grown fodder system. The proportion fed to cattle should nevertheless be adjusted to the total ration and the animals' nutritional needs.

Agathi: Turning Farm Boundaries into Feed Resources

Agathi (Sesbania grandiflora) is a fast-growing, leafy tree that can be planted along suitable farm boundaries. Its leaves are valued as fodder, particularly when green fodder availability declines.

For small farms, boundary planting is an attractive option because it can provide supplementary fodder without allocating an entire field to a tree crop. The planting arrangement should allow sufficient sunlight, access and space for field operations.

Agathi can be established using seeds or other locally recommended planting methods. Young plants require protection from livestock until they are established. Periodic pruning encourages the production of leafy branches and makes harvesting easier.





Nutritional value and feeding

Agathi leaves are a useful source of protein. One study of fodder trees in southern Kerala reported crude protein of approximately 25.24% for Agathi, expressed on a dry-matter basis. The composition of leaves can vary with age, season and growing conditions.

Agathi foliage can be offered as a supplement to grass fodder rather than as the sole feed. Introducing it gradually and feeding it in a balanced ration are important management practices. The tree also illustrates a wider principle of IFS: the farm boundary can contribute to livestock nutrition instead of serving only as a physical demarcation.

Glyricidia: A Dual-Purpose Resource for Cattle and Soil

- Glyricidia (Gliricidiasepium) is a fast-growing multipurpose tree that can be established along farm boundaries and in suitable hedgerows. Its leaves and tender shoots can serve as supplementary fodder, while the pruned biomass can also be used as green-leaf manure.

- This dual purpose makes Glyricidia particularly useful in an integrated farming system.
- Glyricidia can be propagated using seeds or stem cuttings, depending on the planting material and local recommendations. Once established, the trees can be pruned periodically to produce leafy biomass. Spacing and pruning height should be planned to avoid excessive shading of adjacent crops.
- The leaves and tender shoots harvested for fodder can be offered after wilting and mixed with other feeds. Acceptance may vary between animals, so introduction should be gradual.





Nutritional value and feeding

Glyricidia foliage is a useful source of protein, but its composition varies with the age of the leaves, season and growing conditions. It should be considered a supplementary fodder rather than a complete ration.

Some compounds in tree fodders can affect palatability or nutrient utilisation when fed in excessive amounts. Consequently, Glyricidia should be introduced cautiously, mixed with other fodders and used according to veterinary or animal-nutrition guidance.

From cattle feed to green-leaf manure

When the harvested biomass is not required for feeding, suitable Glyricidia leaves can be incorporated into the soil or composted to supply organic matter and nutrients. Its nitrogen-rich foliage can help support nutrient recycling, although the nutrient contribution depends on the quantity applied and its composition.

Thus, a single boundary plantation can serve two complementary purposes: supplementary cattle feed and an organic nutrient resource for crops.

Azolla: A Small Floating Fern with Multiple Uses

Azolla is a small aquatic fern that grows on the surface of still water. Under suitable conditions, it multiplies rapidly and can be harvested frequently.Its usefulness in IFS comes from two distinct roles: supplementary livestock feed and biological nitrogen fixation.

Cultivation

Azolla can be grown in a shallow, properly prepared water unit, such as a lined pit or suitable tank. A shaded location, clean water and appropriate growing conditions help maintain the culture. Recommended nutrient additions and management practices should be followed carefully, and the culture should be protected from contamination.

Regular harvesting prevents overcrowding and helps maintain active growth. The harvested material should be washed to remove excess substrate or unwanted materials before feeding.





Nutritional value and use as cattle feed

Azolla is rich in protein on a dry-matter basis. Crude protein values range from approximately 20% to 30%, depending on the species and growing conditions. However, fresh Azolla contains a high proportion of water, so its protein contribution per kilogram of fresh material is much lower than the dry-matter percentage might suggest.

Azolla should be introduced gradually as a supplementary feed and not used as a replacement for balanced roughage and concentrates. An ICAR study reported that approximately 1.1 kg of fresh Azolla per cow per day was used as a supplement in a field evaluation.

Azolla and biological nitrogen fixation

Azolla forms a symbiotic association with a nitrogen-fixing cyanobacterium, traditionally known as *Anabaena azollae*.

This association enables Azolla to fix atmospheric nitrogen under suitable conditions.

In appropriate farming systems, Azolla can contribute to nutrient management, particularly in rice cultivation. Its use as a bio fertilizer requires suitable cultivation and incorporation practices. The nitrogen fixed by Azolla is not automatically available to crops simply because the fern is present in a separate cattle-feed unit.

This distinction is important: Azolla can serve as supplementary feed and as a biological nitrogen resource, but these are separate uses requiring appropriate management.

Other Feed Resources Available Within IFS

The resources discussed above can be complemented by several other crops and by-products.

- **Fodder cowpea**: A short-duration legume that can be grown in suitable seasons and harvested as green fodder. TNAU reports crude protein values of approximately 20–21% on a dry-matter basis for selected varieties. Its relatively short duration makes it useful for filling seasonal gaps in fodder supply.
- **Guinea grass**: A perennial grass that can be grown under suitable irrigated or rainfed conditions. It provides additional green roughage and can be included in a diversified fodder plan.
- **Fodder sorghum and pearl millet:**These crops can provide green fodder, while their stover may contribute dry roughage after grain harvest. Fodder sorghum requires careful management because young plants or regrowth under certain stress conditions may contain dangerous levels of prussic acid; suspected material should not be fed without appropriate expert assessment.
- **Crop residues:** Paddy straw, maize stover and other suitable residues can contribute to the dry-roughage component of the ration. Their nutritional value differs, and straw alone cannot meet all the requirements of a productive dairy animal. Proper storage and supplementation are essential.
- **Oilseed cakes and concentrate ingredients**: Groundnut cake, cottonseed cake and other suitable feed ingredients can provide additional protein and energy. Their use should be based on ration formulation, feed quality and animal requirements.
- **Moringa and other suitable fodder trees:**Where locally adapted, Moringa and selected fodder trees can provide supplementary leafy biomass. Their inclusion should be planned to maintain a balanced diet and avoid excessive dependence on any one species.

The best combination depends on local availability, animal requirements, cultivation costs and the season.

Bringing the Components Together: A Practical IFS Fodder Plan

A well-planned IFS farm can distribute fodder production across different parts of the holding.

Cumbu Napier may occupy a dedicated fodder plot, with Desmanthus grown in a compatible arrangement or in a nearby plot. Agathi and Glyricidia can be planted along suitable boundaries, while fodder cowpea can fill short-duration gaps when field conditions permit. Crop residues can be stored for dry periods, and Azolla can be cultivated in a separate water unit where suitable.

The daily ration can then combine grass fodder, leguminous fodder, dry roughage and concentrates according to the animal's needs. Clean drinking water and mineral supplementation remain essential.

Farmers should maintain records of fodder harvested, feed offered, feed refusals, milk production, animal health and cultivation costs. These records help identify which components contribute most effectively to the farm.

Fodder planning must also consider seasonal changes. A farm that produces abundant green fodder during the monsoon may experience shortages during hot or dry periods. Staggered sowing, suitable fodder conservation and storage of dry roughage can help bridge these gaps.

A productive dairy enterprise does not begin only in the cattle shed. It begins in the field, along the farm boundary, in the fodder plot and in every well-managed resource that contributes to a balanced ration.

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Volume: 06 Issue No: 10

SOIL ORGANIC MATTER FOR GLOBAL SOIL HEALTH

Article ID: AG-VO6-I10-107

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Abstract

Soil organic matter (SOM) is a fundamental component of soil health and plays a vital role in maintaining global agricultural sustainability. It consists of decomposed plant and animal residues, microbial biomass, and stable organic substances. Soil organic matter improves soil structure, increases water-holding capacity, enhances nutrient availability, promotes microbial activity, and reduces soil erosion [1,2]. It also contributes to carbon sequestration, helping mitigate climate change [2,3]. However, intensive cultivation, deforestation, soil erosion, and crop residue burning are major factors responsible for the depletion of soil organic matter worldwide. Sustainable practices such as compost application, green manuring, crop rotation, cover cropping, residue retention, and conservation agriculture can help restore and maintain soil organic matter [1,2]. Therefore, effective management of soil organic matter is essential for improving soil fertility, enhancing agricultural productivity, conserving biodiversity, and ensuring global soil health and long-term food security.

Keywords: Soil organic matter, soil health, soil fertility, carbon sequestration, sustainable agriculture, global food security.

1. Introduction

Soil is one of the most valuable natural resources on Earth. It supports plant growth, provides nutrients, stores water, and sustains a wide range of living organisms. However,

intensive agriculture, deforestation, soil erosion, and improper land management are causing soil degradation worldwide. Soil organic matter (SOM) is a key indicator of soil health and fertility. It consists of plant and animal residues at different stages of decomposition, microbial biomass, and stable organic substances called humus. Soil organic matter improves the physical, chemical, and biological properties of soil and plays a major role in sustainable agriculture [1,2]. Maintaining adequate soil organic matter is therefore essential for protecting global soil health, improving food security, and building resilience against climate change [2,3].

2. *What is soil organic matter?*

Soil organic matter refers to the organic components present in soil that originate mainly from plant residues, animal remains, roots and microorganisms.

The major components include:

- **Plant and animal residues:** Leaves, roots, crop stubbles, and animal wastes.
- **Microbial biomass:** Living soil microorganisms such as bacteria and fungi.
- **Partially decomposed organic materials:** Materials undergoing breakdown by soil organisms.
- **Humus:** Relatively stable organic matter formed through decomposition and transformation.

Soil organic matter is generally concentrated in the surface soil, where plant residues accumulate and biological activity is high. Its quantity varies with climate, vegetation, soil type, land use, and management practices [1, 2].

3. *Importance of soil organic matter for global soil health*

Soil organic matter is often described as the life-support system of soil because it improves soil fertility, supports biodiversity, and maintains essential soil functions [1, 2].

Improves soil fertility:

Soil organic matter stores and releases essential nutrients such as nitrogen, phosphorus, and sulphur. Decomposition gradually makes these nutrients available to plants, improving crop growth and productivity [1].

Improves soil structure:

Organic matter helps bind soil particles into stable aggregates. This improves porosity, aeration, root penetration, and soil workability while reducing surface crusting and erosion [1, 2].

Enhances water-holding capacity:

Organic matter helps soil absorb and retain water. This supports crop growth during dry periods, improves infiltration, and reduces surface runoff [1].

Supports soil biodiversity:

Organic matter provides food and energy for earthworms, bacteria, fungi, and other soil organisms. These organisms decompose residues, recycle nutrients, and contribute to healthy soil ecosystems [1, 2].

Reduces soil erosion:

Crop residues and improved soil aggregation protect the soil surface from raindrop impact and wind. Better infiltration reduces runoff and the loss of fertile topsoil [1, 2].

4. *Role in Climate Change Mitigation*

Soil organic matter contains a substantial amount of organic carbon derived mainly from plant roots, crop residues, and other biological materials. Soils are important reservoirs of carbon in the global carbon cycle. When organic matter decomposes, some carbon returns to the atmosphere as carbon dioxide, while some can remain stored in soil for varying periods.

Practices such as cover cropping, reduced soil disturbance, agroforestry, and residue retention can help maintain or increase soil organic carbon under suitable conditions. This contributes to climate change mitigation while improving soil resilience [2, 3].

5. *Global Challenges Affecting Soil Organic Matter*

Several unsustainable land-use practices threaten soil organic matter worldwide [1, 2].

- **Intensive tillage:** Can accelerate organic matter decomposition and expose soil to erosion.
- **Crop residue burning:** Removes organic inputs and may reduce soil carbon.
- **Deforestation:** Reduces the supply of plant residues and root biomass.
- **Soil erosion:** Removes organic-matter-rich topsoil.
- **Overgrazing:** Reduces plant cover and increases erosion risk.
- **Unbalanced farming practices:** Continuous crop removal without replenishing organic inputs can gradually deplete soil organic matter.

These processes can reduce soil fertility, weaken soil structure, decrease water storage, and threaten long-term agricultural productivity [1, 2].

6. *Strategies to Improve Soil Organic Matter*

6.1 Organic manures and compost

Apply well-decomposed farmyard manure, compost, and vermicompost to replenish organic materials and improve nutrient cycling [1].

6.2 *Cover crops and green manuring*

Grow cover crops and incorporate suitable green-manure crops to add biomass, protect the soil, and support biological activity [1, 2].

6.3 *Crop residue management*

Retain suitable crop residues as surface mulch instead of burning them. This protects the soil and returns organic material as decomposition proceeds [1, 2].

6.4 *Agroforestry and crop rotation*

Integrate trees into farming systems and rotate crops, including suitable legumes, to diversify organic inputs and maintain soil cover [2, 3].

6.5 *Conservation agriculture*

Minimize unnecessary soil disturbance, maintain soil cover, and use diversified cropping systems to reduce organic matter losses [2].

The effectiveness of these practices depends on local climate, soil conditions, crop type, and the quality and quantity of organic inputs. Integrated management is generally more effective than relying on a single practice [1, 2].

7. *Soil Organic Matter and Sustainable Agriculture*

Maintaining soil organic matter is fundamental to sustainable agriculture because it helps maintain soil productivity over the long term. It supports nutrient cycling, efficient water use, beneficial soil organisms, and improved crop establishment [1, 2]. In tropical regions such as India, high temperatures and favourable moisture conditions can accelerate organic matter decomposition. Regular additions of crop residues, farmyard manure, compost, and green manure are therefore important for maintaining soil organic matter in cultivated soils [1]. Soil testing and monitoring soil organic carbon can help farmers and researchers evaluate changes in soil condition and assess the effectiveness of soil management practices. These efforts contribute to food security, climate resilience, and natural resource conservation [2, 3].

Conclusion

Soil organic matter is a vital component of global soil health and sustainable agricultural

development. It improves soil structure, increases water retention, supports nutrient availability, promotes soil biodiversity, and contributes to carbon storage [1, 2, 3]. However, intensive cultivation, erosion, deforestation, and residue burning can cause its depletion.

Adopting sustainable soil management practices such as compost application, crop rotation, cover cropping, residue retention, agroforestry, and reduced tillage can help conserve and rebuild soil organic matter [1, 2]. Protecting soil organic matter means protecting soil health, agricultural productivity, climate resilience, and the future of global food security.

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Volume: 06 Issue No: 10

DDGS IN SMALL RUMINANT RATIONS: TURNING AN INDUSTRIAL BY-PRODUCT INTO A VALUABLE FEED RESOURCE

Article ID: AG-VO6-I10-108

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Introduction

Feed accounts for a major share of the cost of rearing sheep and goats, particularly when animals are stall-fed or finished for meat. Protein-rich ingredients such as soybean meal and conventional energy feeds can be expensive or fluctuate in availability. Dried distillers grains with solubles (DDGS) are a useful alternative ingredient when they are locally available at a competitive price and are incorporated into a properly balanced ration. DDGS should not be treated as a complete feed on its own; rather, it is a protein- and energy-rich ingredient that can replace part of selected concentrate ingredients.

DDGS is produced during the manufacture of ethanol from cereal grains. After the starch is fermented, the remaining grain components are concentrated. The wet distillers grains are combined with condensed solubles and dried to produce DDGS. Depending on the plant, the raw material may be maize, rice, wheat or a mixture of grains. Therefore, DDGS from different sources may differ considerably in protein, fat, fibre, minerals and digestibility.

Why is DDGS useful in sheep and goat feeding?

The main advantage of DDGS is that it supplies both protein and energy. Much of the starch has been removed during fermentation, while protein, fibre, oil and minerals become concentrated. Some of its protein escapes breakdown in the rumen and may be digested in the small intestine. This can be useful for growing lambs and kids, finishing animals and lactating females when their diets require additional protein and energy.

DDGS can also help make use of an agro-industrial co-product and may reduce dependence on conventional protein meals. However, savings are not automatic. The price of DDGS, its nutrient composition, transport cost and the ingredients it replaces all determine whether the final ration is economical. A ration should be compared on a dry-matter and nutrient basis, rather than simply comparing the price per kilogram as-fed.

Nutrient composition: check the source before use

Dried distillers grains with solubles is a valuable feed ingredient for sheep and goats because it can supply protein, energy and other nutrients. However, its nutritional composition varies according to the raw material used and the manufacturing process. The uploaded studies reported crude protein contents ranging from 29.31 to 44.50% of dry matter, demonstrating the variation between DDGS samples.

Before purchasing DDGS for livestock feeding, farmers should check the source, quality and nutrient composition of the product. Particular attention should be given to dry matter, crude protein, ether extract, crude fibre and total ash. Where laboratory facilities are available, analysis of neutral detergent fibre (NDF), acid detergent fibre (ADF), sulphur and mycotoxins is also advisable.

Excessive sulphur intake can cause health problems in ruminants. Therefore, the sulphur content of DDGS and the complete ration should be considered during feed formulation. DDGS should be stored in a clean, dry and well-ventilated place to prevent moisture absorption, mould growth and deterioration.

The key message for farmers is that all DDGS products are not nutritionally identical. Feed inclusion should be decided according to the quality of the available DDGS, the nutritional requirements of the animals and the composition of the overall ration. Laboratory analysis and appropriate ration formulation help farmers use DDGS safely and economically.

Table 1. Reported proximate composition of DDGS and soybean meal

Nutrient	DDGS	Soybean meal
Dry matter (%)	89.18–91.16	80.1–96.3
Organic matter (% DM)	90.96–95.24	88.8–94.3
Crude protein (% DM)	29.31–44.50	43.8–58.4
Ether extract (% DM)	3.42–11.20	0.3–5.5

Crude fibre (% DM)	5.27–7.85	4.8–10.7
Total ash (% DM)	4.76–9.04	5.7–11.2
Nitrogen-free extract (% DM)	42.05–46.51	14.2–45.4

What the Composition Table Tells Us

The proximate composition of DDGS varies depending on the grain source and processing method. As shown in Table 1, the crude protein content of DDGS ranged from 29.31 to 44.50% of dry matter (DM), indicating its potential as a protein source in sheep and goat diets. The ether extract content ranged from 3.42 to 11.20%, suggesting that DDGS can also contribute dietary energy through fat. Crude fibre ranged from 5.27 to 7.85% and total ash from 4.76 to 9.04% of DM across the reported samples.

In the comparative analysis of rice DDGS and soybean meal, both ingredients had nearly identical crude protein contents (44.50 and 44.47% of DM, respectively). However, rice DDGS contained more ether extract (3.42%) than soybean meal (0.82%) and slightly less crude fibre (5.27 versus 6.70%). These findings indicate that DDGS may serve as an alternative ingredient for partially replacing soybean meal in small-ruminant rations.

However, the nutritional value of DDGS is not uniform across sources. Therefore, its inclusion in sheep and goat diets should be based on the actual nutrient composition of the available product and the nutrient requirements of the animals. Proper ration formulation is essential to maintain balanced nutrient supply and obtain satisfactory growth performance.

What does the research tell us?

Research in growing native ram lambs evaluated DDGS at 0, 10, 20 and 30% of the concentrate mixture in sorghum-stover-based complete rations containing roughage and concentrate in a 50:50 ratio. The 150-day study reported no adverse effect on growth performance, nutrient utilisation or carcass characteristics. Average daily gain increased numerically with DDGS, although the differences were not statistically significant. Feed cost per kilogram of live-weight gain was lowest in the group receiving 20% DDGS in the concentrate mixture, followed by the 30% group. These results support DDGS as a useful ingredient in balanced ram-lamb diets, but the levels refer to the concentrate mixture and should not be confused with the percentage of the whole ration.

An Indian study in growing Osmanabadi goats examined rice DDGS as a partial replacement for soybean meal. The 90-day trial compared a control diet with diets containing 10

or 15% rice DDGS in the concentrate mixture. Growth, dry-matter intake and nutrient utilisation were not adversely affected. Feed cost per kilogram of live-weight gain declined from ₹159.90 in the control group to ₹154.99 and ₹151.71 in the 10 and 15% groups, respectively, under the prices used in that study. The 15% group recorded the highest calculated net profit per goat. These figures are specific to the trial's ingredients and prices and should not be used as current market estimates.

A 2023 meta-analysis of 33 studies involving 940 meat sheep found that DDGS feeding was associated overall with higher final body weight and improved digestibility of neutral detergent fibre and fat. Its dose-response analysis recommended keeping DDGS at about 20% or less of the total diet to reduce the risk of undesirable effects on rumen fermentation, nitrogen use and meat colour. Other studies have reported benefits at different inclusion levels, illustrating why source, diet composition, breed and production stage matter. Evidence from one species or DDGS source should not be assumed to apply identically to every flock.

How much DDGS can be included?

For practical farm use, begin conservatively and formulate the ration according to the nutrient requirement and the DDGS analysis. The Indian goat trial supports 10–15% rice DDGS in the concentrate mixture as a studied option for growing Osmanabadi goats. The native ram-lamb trial studied 10–30% DDGS in the concentrate mixture and found no adverse effects under its experimental conditions, with the most favourable feed cost per kilogram of gain at 20%. In contrast, the sheep meta-analysis advises caution above approximately 20% of the total diet on a dry-matter basis.

These percentages have different denominators: percentage of concentrate mixture is not the same as percentage of the complete ration. For example, when concentrate is half of the ration, DDGS at 20% of the concentrate contributes approximately 10% of the complete ration on the same basis. Always state whether a recommendation refers to the concentrate or the total diet, and calculate inclusion on a dry-matter basis when moisture differs between ingredients.

There is no single inclusion level suitable for every farm. A nutritionist should balance the ration for dry matter, crude protein, energy, effective fibre, minerals and the animal's stage of production. Introduce DDGS gradually over 7–14 days while monitoring feed intake, dung consistency and animal performance.

Important precautions for safe feeding

- Check the source and consistency: buy from a reliable supplier and ask for a recent nutrient analysis. Protein, fat, fibre, phosphorus and sulphur can vary between plants and batches.
- Store it properly: keep DDGS dry, covered and protected from rain, damp floors, rodents and mould. Reject material with a musty smell, visible mould, heating or unusual discolouration.
- Balance minerals: DDGS can contain substantial phosphorus and sulphur. Consider the full ration and water supply, and obtain professional advice on mineral balance, particularly for male sheep and goats because urinary calculi risk is influenced by the overall diet.
- Do not remove roughage: maintain adequate good-quality forage or roughage. DDGS is an ingredient, not a replacement for all forage or a complete mineral mixture.
- Avoid sudden changes and overfeeding: gradual adaptation helps animals adjust. High inclusion can unbalance the ration, reduce fibre digestion in some circumstances or increase nitrogen losses.
- Review economics regularly: compare the cost per kilogram of dry matter and the cost per unit of usable protein and energy. Include transport, storage losses and any additional balancing ingredients.

A simple decision guide for farmers

Before using DDGS, ask four questions: (1) Is it available consistently and at a competitive delivered price? (2) Has its nutrient composition been checked? (3) Which ingredient will it replace, and will the complete ration still meet the animal's needs? (4) Can the flock be monitored for intake, growth and health after introduction? If these questions cannot be answered, obtain advice from a veterinarian or animal nutritionist before increasing the inclusion level.

For growing lambs and kids, weigh a sample of animals at regular intervals and record feed offered and refused. For breeding females, assess body condition and reproductive performance rather than relying on weight alone. If intake drops, diarrhoea develops or performance deteriorates after introduction, review the ingredient quality and the whole ration promptly.

Practical example: understanding the percentage

Suppose a ration contains 50 kg of concentrate mixture and a farmer plans to include DDGS at 20% of that mixture. The mixture would contain 10 kg of DDGS and 40 kg of the other concentrate ingredients, before the ration is adjusted to meet nutrient requirements. If the animals are offered a complete ration made of 50% concentrate and 50% roughage on a dry-matter basis, this 20% inclusion in the concentrate would contribute approximately 10% of the complete ration dry matter. This is only an example to explain the calculation, not a ready-made ration. The other ingredients must be reformulated because DDGS changes the protein, energy, fibre, fat and mineral content.

A second important point is moisture. If DDGS and other ingredients have different moisture contents, the as-fed weight is not directly comparable. Dry-matter basis allows a fair comparison. For instance, 10 kg of a dry ingredient contributes more actual feed solids than 10 kg of a wet ingredient. Where a laboratory report gives nutrients on a dry-matter basis, the nutritionist should convert ingredient quantities to dry matter before finalising the ration.

What to look for in a DDGS analysis

A basic laboratory report should ideally include dry matter, crude protein, ether extract (fat), crude fibre or neutral detergent fibre, ash, calcium, phosphorus and sulphur. Depending on the source and risk, additional testing may be advised. Do not assume that the nutrient values of corn DDGS are identical to those of rice DDGS. The grain used, fermentation process, drying temperature and amount of solubles added back can alter the final product. Excessive heat during processing can also reduce the availability of some protein, so crude protein alone does not describe the whole feeding value.

When a new batch arrives, inspect it before unloading and keep a small representative sample. If the appearance, smell or texture differs from the previous batch, do not mix it immediately with the stored material. Keep batch records, supplier details and purchase price. These simple practices make it easier to identify a quality problem and compare the real performance of different batches.

Monitoring after introduction

During the first two weeks, check whether animals approach the feed normally and whether refusals increase. Observe dung consistency, rumination, general activity and any signs of digestive upset. Weigh growing animals at the start and at regular intervals under similar

conditions. Record the amount of concentrate and roughage offered and the refusals, so that intake and cost per kilogram of live-weight gain can be estimated. Compare animals of similar age, sex and starting weight where possible.

A lower purchase price does not always mean a lower cost of production. If a cheap batch is low in usable nutrients or requires extra ingredients to balance the ration, the apparent saving may disappear. The most useful comparison is the cost of a balanced ration per unit of animal performance. For small flocks, purchasing a consistent quantity from a trusted supplier and sharing transport with neighbouring farmers may improve practicality, provided storage remains dry and hygienic.

Conclusion

DDGS offers sheep and goat farmers a potential way to supply protein and energy while making use of an agro-industrial by-product. Studies in native ram lambs and Osmanabadi goats show that moderate inclusion can be compatible with satisfactory performance and may lower feed cost when the ingredient is competitively priced. The safest approach is to test the material, introduce it gradually, retain adequate roughage and formulate the complete ration. Start with evidence-supported moderate levels and adjust only with nutritionist guidance; the best inclusion rate is the one that maintains animal health and performance while reducing the actual cost of production.

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Volume: 06 Issue No: 10

CROP RESIDUE MANAGEMENT FOR SUSTAINABLE AGRICULTURE: CONSEQUENCES OF BURNING, IN-SITU PRACTICES AND EX-SITU UTILISATION

Article ID: AG-VO6-I10-109

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Abstract

Crop residues are the plant parts left in the field after the economic part of a crop has been harvested, and they are generated in very large quantities in Asia. China is reported as the leading global producer (about 864.3 million tons in 2025), while India generates about 762.8 Mt of residue annually, 70% of it from cereals. A narrow sowing window, limited machinery, high management cost and labour constraints push farmers towards open-field burning. For rice residue, burning removes all of the carbon, 90% of the nitrogen, 25% of the phosphorus, 20% of the potassium and 60% of the sulphur, releases greenhouse gases and particulates, endangers human health and causes economic losses of nearly US$ 1.5 billion over five years. This article synthesises the supplied material on in-situ management (retention, surface mulching, incorporation, conservation agriculture, zero/reduced tillage) and ex-situ utilisation (livestock feed, composting, mushroom cultivation, biochar, biofuels, biogas), together with enabling machinery, national policy and two case studies. A 17 year study in the Indo-Gangetic Plains reported 35-87% higher carbon sequestration and 66-84% lower GHG emissions under conservation tillage with residue retention, and a study in Uttar Pradesh reported 7.01-23.90% higher yields. Residues are therefore best managed as a resource rather than as waste.

Keywords: *crop residue management; residue burning; in-situ management; ex-situ utilisation; conservation agriculture; composting; biochar; circular bioeconomy*

1. Introduction

Crop residues are the plant parts left in the field after harvesting the economic part of an agricultural crop (Shinde *et al.*, 2022). They comprise stalks, leaves, stems, seed pods and stubbles remaining once the grain, seed or fibre has been removed, and a second group of materials, such as groundnut shells, husk, bagasse, molasses and oil cakes, remains after a crop is processed. Crop residue management is the systematic handling of these materials after harvest through retention, incorporation, removal or recycling, with the aim of conserving soil moisture, recycling plant nutrients, improving soil health and sustaining crop productivity (Gupta *et al.*, 2018; Singh and Mina, 2022). Handled strategically, residues also help to prevent erosion and provide ecological and economic benefits.

The source material traces the way in which residues have been perceived. In early, pre-industrial agriculture they were left in the field or burned because their value was not understood, and mechanisation during the Industrial Revolution still overlooked the benefits of retaining them in soil. The development of soil science in the late nineteenth century drew attention to organic matter, including crop residues, for soil fertility and structure, but the Green Revolution of the mid-twentieth century, with its high-yielding varieties, fertiliser, seed and irrigation, again directed attention to maximising yield at the expense of sustainable practices. Environmental awareness in the late twentieth century, driven by concern over soil erosion, runoff, evapotranspiration and greenhouse-gas emissions, renewed interest in such practices. Advances in precision agriculture and machinery have since made conservation tillage, cover cropping, residue mulching and energy generation feasible, and residue management is now regarded as a key strategy for improving soil health, reducing greenhouse-gas emissions and building resilience to extreme weather under climate change. This article synthesises the available evidence on residue generation, the consequences of burning, and the in-situ and ex-situ management options.

2. Residue Generation and Status in India

China is reported as the top global producer of agricultural residues, with an estimated 864.3 million tons in 2025, and India produces about 762.8 Mt of crop residue per year, of which cereals contribute 70% (rice 34% and wheat 22%). Wheat (183.7 Mt), rice (178.3 Mt) and sugarcane (173.7 Mt) are the major contributors (Shanmugam *et al.*, 2025). A different estimate puts national production at over 500 Mt of crop waste, of which 100 Mt is burned (Lan *et al.*,

2022). Of the 500 Mt produced annually, 234 Mt is surplus, 30% of which is contributed by rice and wheat; approximately 16% of total residues are burned, and rice and wheat account for 62% of this burned fraction. Dry-biomass shares by crop (Dutta *et al.*, 2022) are led by rice (33%), wheat (21%), sugarcane (17%) and cotton (10%) (Fig. 1a), whereas the major crops whose residues are burned are rice (33%), wheat (21%), sugarcane (19%) and oilseeds (5%). The quantity of residue per tonne of grain differs among crops: 1.2-1.5 for rice, 1.5 for wheat, 1.3 for maize, 0.38 for sugarcane, 1.22 for millet and 2.4 for cotton. Generation, surplus and burning vary considerably among states, and a considerable surplus remains vulnerable to open-field burning (Porichha *et al.*, 2021; Kumar *et al.*, 2023). Among the five major states in Table 1, Uttar Pradesh generates the most residue (59.97 Mt) and Punjab the largest surplus (24.83 Mt) and 19.65 Mt burned, while the burned quantity reported for Uttar Pradesh is inconsistent in the source. Haryana, Maharashtra and Madhya Pradesh report 9.08, 7.42 and 6.91 Mt burned, respectively.

Table 1. Residue generation, surplus and burning in five major Indian states (Mt)

S. No.	State	Residue generation	Residue surplus	Residue burned
1	Punjab	50.75	24.83	19.65
2	Uttar Pradesh	59.97	13.53	11.92[a]
3	Haryana	27.83	11.22	9.08
4	Maharashtra	46.45	14.67	7.42
5	Madhya Pradesh	33.18	10.22	6.91[b]

Source: Porichha *et al.* (2021) and Kumar *et al.* (2023)

Residues also differ in their value as nutrient sources (Table 2). Wheat residue has the highest carbon content (44%) and the widest C:N (86) and C:P (628) ratios, followed closely by cotton (C:N 84), whereas groundnut has the highest nitrogen (1.92%) and the narrowest C:N ratio (21). Soybean has the highest phosphorus (0.25%) and sulphur (0.27%) contents and the narrowest C:P ratio (156), and cotton has the highest potassium content (1.67%). The source states that composting cannot start when the C:N ratio is wide (100:1) and that a ratio of 30:1 is ideal, so the C:N values in Table 2 indicate how readily different residues might be composted.

Table 2. Chemical composition of different crop residues (nutrient content, %)

Crop residue	C	N	P	K	S	C:N	C:P
Wheat	44	0.51	0.07	1.48	0.21	86	628
Pigeonpea	42	1.26	0.09	0.41	0.26	33	466
Groundnut	41	1.92	0.20	0.82	0.25	21	205
Maize	43	0.81	0.13	0.88	0.22	53	330
Soybean	39	1.27	0.25	0.66	0.27	31	156
Cotton	42	0.50	0.21	1.67	0.24	84	200

Source: Behera *et al.* (2021), as reproduced in the supplied document. C:N and C:P are ratios.

3. Consequences of Residue Burning

Crop residue burning has emerged as a major environmental challenge affecting soil, plant and environmental sustainability. It contributes to greenhouse-gas emissions and to degradation of soil health, with loss of soil organic matter and carbon, nutrient losses and reduced microbial activity and diversity (Raza *et al.*, 2022). Combustion can release almost all of the carbon, 80-90% of the nitrogen, 25% of the phosphorus, 20-25% of the potassium and about 50% of the sulphur (Dutta *et al.*, 2022)..

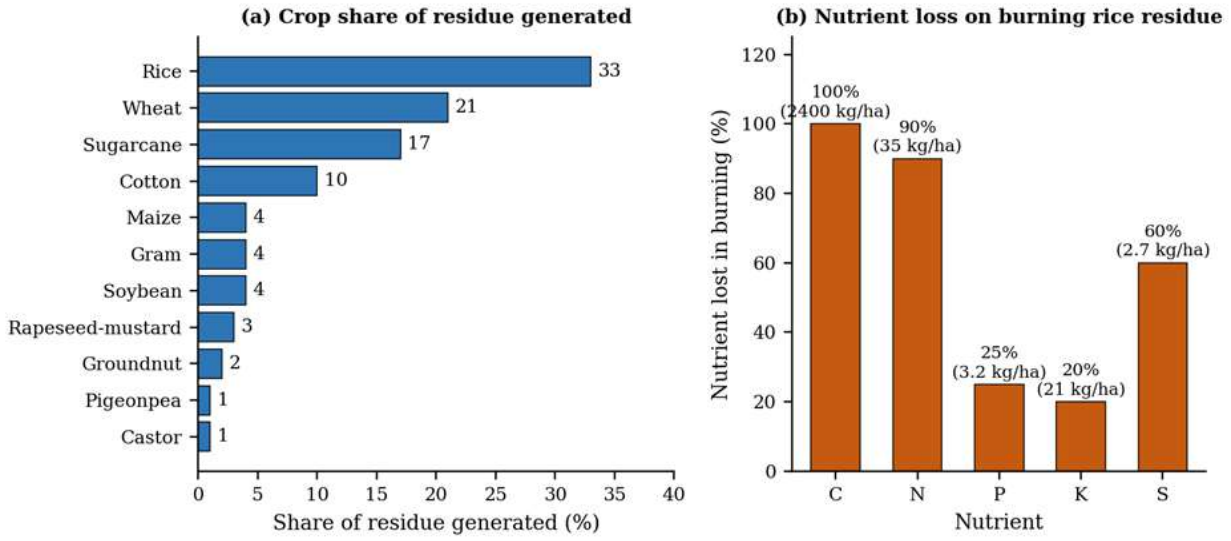


Figure 1. (a) Share of residue generated by crop in India (%; Dutta *et al.*, 2022). (b) Percentage of each nutrient lost on burning rice residue, with absolute loss in kg/ha in parentheses (Porichha *et al.*, 2021). Values are those given in the supplied document.

Quantitative data for rice straw (Porichha *et al.*, 2021) show the same pattern (Fig. 1b): straw containing 400 g C, 6.5 g N, 2.1 g P, 17.5 g K and 0.75 g S per kg loses 100% of its carbon (2400 kg/ha), 90% of its nitrogen (35 kg/ha), 25% of its phosphorus (3.2 kg/ha), 20% of its potassium (21 kg/ha) and 60% of its sulphur (2.7 kg/ha). Burning also elevates soil temperature, which kills microorganisms, and leaves land more vulnerable to erosion

Emissions and air quality are further affected. About 70% CO_2, 7% CO and 0.7% CH_4 of the carbon contained in rice straw are emitted on burning, and the smoke carries NH_3, NOx, SOx, non-methane hydrocarbons, volatile and semi-volatile organic compounds and particulate matter, increasing black carbon and aerosol loading and degrading regional air quality (Sahara *et al.*, 2025). Long-term exposure to particle pollution may also cause bifacial necrosis or chlorosis in plants. For people living near burning areas, smoke increases the risk of respiratory and cardiovascular problems, eye and skin irritation, allergic reactions, reduced lung function, asthma and chronic bronchitis (Raz *et al.*, 2022). The source also links burning with smog and haze, climate change, increased mortality, productivity loss and reduced income of farmers. Economically, the projected loss from burning over the past five years is close to US$ 1.5 billion, and the value of agricultural produce lost is about ₹5,000 million (₹500 crore) per year (Singh *et al.*, 2022). Burning persists because of several practical pressures: the narrow sowing window between two crops, limited availability of residue-management machinery, the high cost of residue management, labour constraints, the need for rapid field clearance, increasing cropping intensity and limited access to alternative uses (Kumar *et al.*, 2023; Erbaugh *et al.*, 2024). Addressing burning therefore requires management options that are timely, affordable and accessible, not only awareness of harm.

4. Residue Management: Objectives and Framework

Residues are a substantial source of organic carbon and plant nutrients and can be retained, incorporated, recycled or converted into useful products that improve soil health and generate added value (Sarkar, 2024). The need for management is therefore to prevent burning and air pollution, recycle nutrients and organic carbon, improve soil health and fertility, conserve soil moisture, improve resource-use efficiency, reduce greenhouse-gas emissions and convert waste into useful resources (Parshad *et al.*, 2025). Its goals are soil conservation (reduced wind and water erosion and maintained organic matter), soil quality (moisture retention, aeration, infiltration and structure), nutrient cycling, environmental benefits and economic benefits

through higher farm efficiency and potential income. As a soil amendment, residues improve structure and water-holding capacity, control erosion, moderate soil temperature, enhance microbial activity, regulate nutrient cycling and reduce evaporation. The source infographic links these outcomes with carbon neutrality, land degradation neutrality and Sustainable Development Goals 7, 12 and 13. Figure 2 summarises the pathways discussed in the remainder of the article.

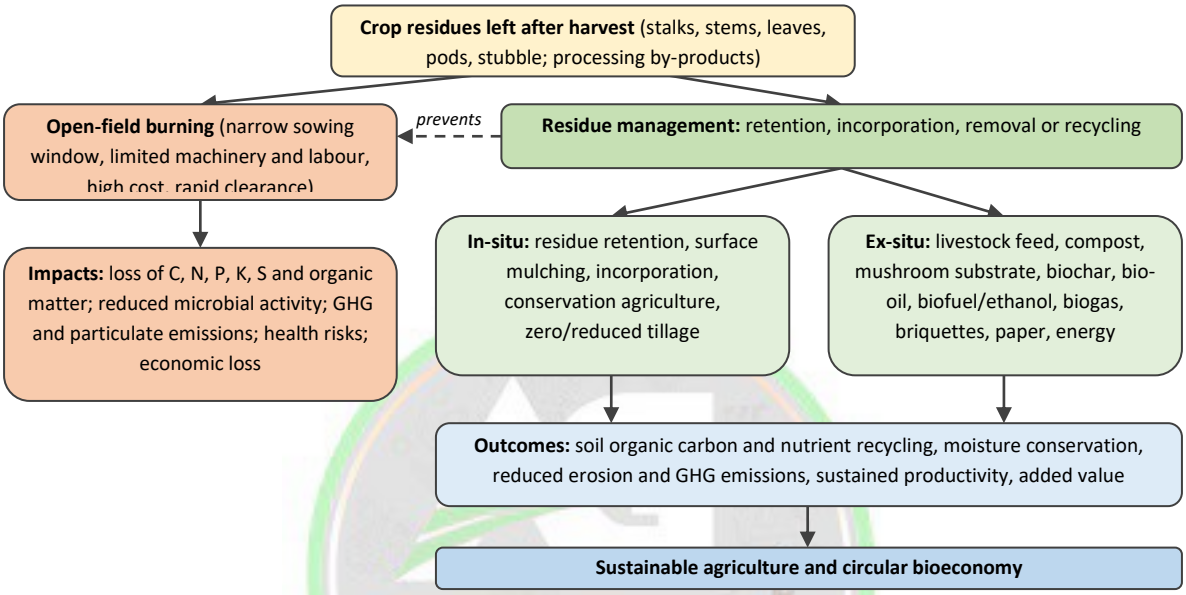


Figure 2. Flowchart of residue fate after harvest: open-field burning and its impacts versus in-situ and ex-situ management leading to sustainable agriculture, as described in the supplied document (Kumar *et al.*, 2023; Parshad *et al.*, 2025).

5. In-situ Residue Management

In-situ management keeps residues in the field through residue retention, surface mulching, incorporation, conservation agriculture and zero or reduced tillage with residue retention. Its benefits are improved soil organic carbon, nutrient recycling, moisture conservation, reduced erosion, improved soil health and sustained crop productivity (Kumar *et al.*, 2023; Ahmad *et al.*, 2024). Surface mulching spreads crop stalks, leaves or straw over the soil to conserve moisture, regulate soil temperature, prevent erosion and suppress weeds; although it may be tedious, it is effective for a cropping season. Rice straw mulch boosted wheat grain production, reduced crop consumptive use by 3-11% and improved water-use efficiency by 25% compared with no mulch (Chakraborty *et al.*, 2010). The source lists enhanced soil structure, erosion control, improved soil health, moisture conservation, weed suppression, nutrient recycling and environmental benefits as advantages of retaining residues. Its

disadvantages are that residues can harbour pests and diseases, the cost of machinery, nitrogen immobilisation, delayed crop emergence, the need for careful management and hurdles to adoption by farmers. Implements for residue management include the straw chopper, Happy Seeder, zero-till seed-cum-fertiliser drill and baler, as well as the Super Straw Management System (SMS), which cuts straw into small pieces and scatters it behind the combine.

6. Ex-situ Residue Utilisation

Residues removed from the field can be used as livestock feed, for compost production and mushroom cultivation, and converted to biochar, bio-oil, biofuel and ethanol, briquettes and pellets, paper and other value-added products, or used for energy production (Parshad *et al.*, 2025).

6.1 Livestock feed

Rice and wheat straw are abundant and commonly used as basic fibrous feed for cattle, buffalo and sheep. Sorghum stover is a valuable feed, especially in semi-arid and tropical regions, and is known for its keeping quality. Cassava and yam peels, cowpea husk, maize and sorghum fermentation wastes and various kitchen wastes are also used, particularly for small ruminants.

6.2 Composting

Compost is a mass of rotted organic matter made from waste, and composting is the natural decomposition of organic matter by microorganisms under controlled conditions. The C:N ratio determines whether composting begins: a wide ratio (100:1) prevents it, and a narrow ratio of 30:1 is ideal. Four methods are described in Table 3. The Coimbatore method is anaerobic and the NADEP method relies on aerobic decomposition with air-circulation holes in the tank walls, whereas the source does not state the aeration condition of the Indore and Bangalore methods.

Table 3. Composting methods described in the supplied document

Method	Pit or tank size	Materials and procedure	Duration
Indore	Length 4-5 m, width 1.5-2 m, depth 1 m	4.5 kg dung, 3.5 kg urine-soaked mud and 4.5 kg inoculum (basis not stated)	Not stated
Coimbatore	3.6 m × 1.8 m ×	5-10 kg cow dung in 2.5-5.0 L	8-10 weeks

(anaerobic)	1 m	water and 0.5-1.0 kg fine bone meal sprinkled uniformly; layers repeated to raise the heap 0.75 m, then plastered with wet mud	undisturbed; plaster removed, material moistened, turned and heaped under shade for 4-5 months
Bangalore (C.N. Acharya)	Trench 3-3.5 m × 1.5-2 m × 1 m	25 cm of dry waste, then thick cow-dung suspension; layers repeated until 1 m above ground; exposed, turned, then plastered with wet mud	15 days before turning; 5 months undisturbed
NADEP (aerobic)	10 ft × 6 ft × 3 ft; 9-inch walls with 7-inch air holes; near cattle shed	Farm residues 1400-1500 kg, cattle dung 90-100 kg, dry sieved soil 1750 kg, water 1500-2000; layers of residue (to 6 inches), dung-gobar-gas slurry (4-5 kg in 125-150 L water) and 50-60 kg sieved soil	Not stated

6.3 Mushroom cultivation

Paddy straw is the major substrate for mycelium growth compared with other crop residues and is used for oyster and milky mushrooms. Sorghum and cumbu stalks can also be used, but because they degrade quickly after sterilisation and are prone to contamination they are not preferred. Wheat straw is widely used for button mushroom cultivation because of its effective composting and nutrient content.

6.4 Biochar, biofuels and biogas

Biochar is a carbon-rich charcoal produced by heating organic material such as plant waste in a low-oxygen environment. Dry, carbon-rich residues, including rice husks, wheat, maize and cotton stalks, corn cobs, cassava rhizomes and wood chips, are subjected to slow pyrolysis at 300-700 °C in sealed or semi-sealed containers, such as portable kilns or drum-based systems, which limit oxygen and prevent full combustion. After volatile gases are driven off, the fire is extinguished, often by cooling with water, and the remaining char is collected as biochar; wheat straw, corn stover and rice husks all serve as feedstock (Seo *et al.*, 2022). Residues from

rice, wheat, maize, sugarcane, cotton and oilseeds are widely used for biofuel because of their sugar, starch or oil content. Sugarcane and sugarbeet, rich in sugar, and maize, rich in starch, give bioethanol; soybean and rapeseed, rich in oil, give biodiesel; and cellulose- and lignin-rich rice, wheat and cotton residues are used for bioethanol through biomass pretreatment, acid hydrolysis and fermentation, and downstream processing. In bio-methanation, residues such as rice straw and cotton stalks are mixed with water into a slurry and digested anaerobically by microorganisms through hydrolysis, acidogenesis, acetogenesis and methanogenesis, yielding methane-rich biogas for cooking and electricity and a liquid digestate that serves as organic fertiliser.

7. Field Evidence, Policy Support and Challenges

Two case studies illustrate the benefits. A 17-year field study in the western Indo-Gangetic Plains showed that conservation tillage combined with residue retention or incorporation increased carbon sequestration by 35-87% and decreased GHG emissions by 66–84% compared with conventional practices, with zero tillage plus residue retention the most effective option for carbon management (Fagodiya *et al.*, 2025). In Uttar Pradesh, mechanised practices including the Happy Seeder, Super Seeder, zero tillage and drum seeder reduced residue burning and improved resource-use efficiency, with crop yield improvements of 7.01-23.90% and cost savings of up to ₹30,005 per ha; zero-tillage area rose from 238 ha in 2005-06 to 5,832 ha in 2019-20 (Anushi *et al.*, 2026). The National Policy for Management of Crop Residues (NPMCR, 2014) promotes sustainable management by giving financial support to farmers who adopt alternative uses such as biomass-based power generation, biofuels and fodder, encouraging innovative technologies and machinery, and raising awareness of the harmful effects of burning. The constraints discussed above, including machinery and labour limits, cost, short turnaround between crops and adoption hurdles, suggest that such support is most useful when it addresses these specific barriers.

8. Conclusion

Crop residue management is a key component of sustainable agriculture, allowing residues to be recycled and used rather than burned or wasted. Open burning destroys carbon and nutrients, pollutes air, harms health and costs the agricultural sector heavily. In-situ practices improve soil health and fertility, whereas ex-situ routes convert residues into feed, compost, mushroom substrate, biochar, biofuels and biogas. Integrated residue management can therefore

enhance resource-use efficiency, support resilient farming systems and promote a circular bioeconomy, provided that machinery, cost and adoption barriers are addressed.

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Volume: 06 Issue No: 10

SOIL CARBON CREDIT: A SUSTAINABLE SOLUTION TO CLIMATE CHANGE

Article ID: AG-VO6-I10-110

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Abstract:

Soils are more than a medium for plant growth: they are a major store of carbon and a living system that supports food production, water regulation and biodiversity. Soil carbon sequestration occurs when carbon captured by plants through photosynthesis enters the soil through roots, crop residues and other organic materials and is retained as soil organic carbon (SOC). Soil carbon credits aim to reward land managers for measurable, additional and durable climate benefits created by improved land management. Practices such as cover cropping, residue retention, diverse crop rotations, reduced soil disturbance, agroforestry and suitable organic amendments can increase carbon inputs and improve soil function. However, soil carbon changes slowly and varies with soil type, climate, depth and management. Credible crediting therefore requires careful baselines, repeated measurement, transparent accounting, independent verification and safeguards against carbon loss. Soil carbon credits can help align climate action with better soil health and farmer income, but they are not a substitute for reducing fossil-fuel emissions. This article explains the science, practices, crediting process, opportunities and limitations of soil carbon credits, with relevance to sustainable agriculture in India.

Keywords: Soil carbon credit, soil organic carbon, carbon sequestration, climate change, regenerative agriculture, carbon farming, monitoring, reporting and verification (MRV)

1. Introduction

Climate change is driven largely by the accumulation of greenhouse gases, especially carbon dioxide (CO_2), in the atmosphere. Land use and farming can either release carbon or help store it. Plants absorb atmospheric CO_2 during photosynthesis. A portion of this carbon reaches the soil through roots, root exudates, fallen leaves, crop residues and decomposing organic matter. Some of it is returned to the atmosphere by respiration and decomposition, while another portion becomes part of soil organic carbon. The amount retained depends on the balance between carbon inputs, decomposition, soil conditions and disturbance [1,2].

Soil organic carbon is important for climate mitigation and for everyday farming. It contributes to aggregation, nutrient cycling, water-holding capacity and biological activity. The Food and Agriculture Organization (FAO) identifies the protection and increase of SOC as an important part of sustainable soil management and resilient food systems [1]. Soil carbon credits connect this environmental value with a possible financial incentive: when a project demonstrates a verified climate benefit under an accepted methodology, credits may be issued and purchased by organisations seeking to compensate for emissions. The quality of those credits depends on the evidence behind them.

2. What is a soil carbon credit?

A soil carbon credit is a tradable unit representing a quantified climate benefit from a project, under the rules of a particular carbon-crediting programme. In many programmes, one credit represents one metric tonne of carbon dioxide equivalent (t CO_2e) removed from the atmosphere or emissions avoided. The precise meaning depends on the programme and its methodology. A credit should not be issued simply because a farmer follows a recommended practice; the project must estimate or measure the net climate benefit compared with a credible baseline and account for uncertainty and risks.

Carbon farming refers to land-management activities intended to increase carbon storage or reduce greenhouse-gas emissions. Soil carbon credits may provide an additional source of income for farmers who adopt eligible practices, collect required records and participate in a monitoring programme. Payments are not guaranteed: they depend on project rules, verified outcomes, market demand, costs and the contract between farmers and project developers.

3. How does soil carbon sequestration work?

The process begins when plants capture CO_2 and convert it into organic compounds. Carbon enters the soil through roots, root turnover, root exudates, crop residues, manure or compost where appropriate. Soil organisms decompose these materials. Some carbon is released as CO_2, while some is transformed into microbial products or becomes associated with soil minerals and aggregates. These processes can slow the return of carbon to the atmosphere. The amount stored is not unlimited: it is influenced by soil texture and mineralogy, temperature, rainfall, plant productivity, drainage, nutrient availability and previous land use [2,3].

It is important to distinguish carbon concentration from carbon stock. A reliable assessment of soil carbon stocks generally needs SOC concentration, bulk density, sampling depth and the amount of coarse fragments to be considered. Sampling at consistent depths and times, with suitable statistical design, helps reduce misleading comparisons. Changes in SOC can be small relative to the natural variation within a field, so repeated measurements and uncertainty estimates are essential.

4. Farming practices that can support soil carbon

Cover crops and living roots: Growing crops between main cropping seasons can extend the period of photosynthesis, add roots and residues, protect the soil surface and reduce erosion.

Residue retention and organic inputs: Returning suitable crop residues, compost or well-managed manure can increase organic carbon inputs. The material should be used according to local nutrient needs and food-safety guidance.

Reduced or strategic tillage: Reducing soil disturbance can protect aggregates and reduce erosion. Outcomes vary by soil and climate, and a change in tillage alone does not guarantee a net increase in whole-profile carbon.

Diverse crop rotations and legumes: Rotations that include deep-rooted crops, legumes or perennial phases can increase the diversity and timing of carbon inputs while supporting nutrient cycling.

Agroforestry and perennial vegetation: Trees and perennial plants add carbon through roots, litter and woody biomass. Benefits depend on species, spacing, water availability and competition with crops.

Erosion control and improved grazing: Maintaining ground cover, managing stocking rates and restoring degraded land can prevent carbon-rich topsoil from being lost and may improve carbon inputs.

These practices should be selected for local suitability rather than applied as a universal checklist. For example, residue retention may compete with livestock feed needs, while cover crops may require careful water management in dry regions. The strongest projects combine climate benefits with practical agronomy and farmer priorities.

5. From a field practice to a verified credit

A credible soil carbon project typically follows a sequence of steps: (i) define the project area and eligible activities; (ii) establish a baseline describing what is likely to happen without the project; (iii) prepare a monitoring plan and collect soil, management and relevant emissions data; (iv) estimate changes in carbon stocks and other greenhouse-gas emissions; (v) account for uncertainty, leakage and reversal risk; and (vi) arrange independent validation or verification as required by the programme. Only after the programme's requirements are met can credits be issued.

Monitoring, reporting and verification (MRV) is the backbone of the process. Monitoring gathers field and management data; reporting documents methods, assumptions and results; verification checks whether the claims are supported by evidence. Soil sampling may be combined with laboratory analysis, models, remote sensing and farm records. Models can help cover large areas, but they must be appropriate for local conditions and checked against reliable field data [4].

6. What makes a soil carbon credit trustworthy?

Additionality: The carbon benefit should be greater than what would reasonably have happened without the project.

Permanence: Stored carbon should remain stored for the period required by the programme, while recognising that drought, fire, erosion or a return to intensive disturbance can reverse gains.

Leakage: The project should check whether emissions or damaging activities have simply shifted to another location.

Measurement and uncertainty: Sampling error, spatial variation and model uncertainty must be quantified and treated conservatively.

Transparent accounting: Methods, assumptions, fees, risks and the division of revenue should be clearly explained to participating farmers.

These safeguards matter because soil carbon is dynamic. Research has shown that short measurement periods and unusual weather can make it difficult to distinguish management-driven gains from changes caused by rainfall or other climate conditions. A 2024 analysis of Australian soil carbon projects highlighted the risk of crediting temporary gains associated with exceptionally wet conditions and recommended stronger safeguards and longer measurement periods [5]. The lesson is not that soil carbon credits cannot work, but that credible claims require robust evidence over time.

7. Opportunities for India

India has diverse agricultural soils, climates and farming systems, so soil carbon projects need locally suitable methods. Opportunities may include improving organic matter management, reducing erosion, integrating trees where appropriate, diversifying rotations, using cover crops in suitable seasons, restoring degraded lands and improving grazing management. These activities can support soil structure, moisture retention and nutrient cycling while contributing to climate goals. A 2024 overview of Indian agriculture discusses the potential for capturing atmospheric CO_2 and creating ways for farmers to benefit from carbon credits [6].

For small and marginal farmers, the main barriers may include the cost of soil testing, complex documentation, uncertain payments, land-tenure issues and the time needed to demonstrate a change. Farmer groups, cooperatives, farmer-producer organisations, research institutions and trusted project developers can help pool sampling and verification costs. Contracts should clearly explain who owns the credits, what practices are required, how payments are calculated, how long commitments last and what happens if carbon stocks decline. Participation should be informed and voluntary.

8. Benefits beyond carbon

A well-designed project can deliver more than a carbon claim. Increasing soil organic matter and protecting the soil surface may improve aggregate stability, reduce erosion, support soil organisms, improve infiltration and help crops use water and nutrients more efficiently. Diversified systems can also support biodiversity and resilience. These outcomes are not automatic, and they should be measured or described honestly rather than assumed from the

presence of a particular practice. The best projects reward verified climate benefits while maintaining food production and improving long-term soil health [1,2].

9. Challenges and the way forward

The major challenges are the slow pace of SOC change, large field-to-field variation, the cost of repeated sampling, uncertainty in models, and the possibility that stored carbon may later be lost. Different crediting methods can also produce different estimates from similar data, making transparent standards important [3,7]. A project that focuses only on selling credits may overlook other greenhouse gases, such as nitrous oxide from nitrogen fertilisers, or may encourage practices that are poorly suited to local conditions.

Improvement requires long-term field trials, locally calibrated models, consistent sampling protocols, open reporting of uncertainty and independent verification. Credit programmes should use conservative assumptions, account for the full project greenhouse-gas balance where required, and set aside appropriate safeguards for reversal risk. Farmers need fair contracts, accessible technical support and a clear share of the financial value. Public policies should also support soil testing, extension services and sustainable practices, including for farmers who are not able to enter carbon markets.

10. Conclusion

Soil carbon credits offer a promising way to connect climate action with sustainable agriculture. By encouraging practices that return carbon to the soil and protect existing stocks, they can potentially contribute to climate mitigation, healthier soils and additional farmer income. Their value, however, depends on the quality of the science and the fairness of the system. Carbon should be credited only when benefits are additional, measured or estimated transparently, independently verified and protected against reversal. Soil carbon credits must complement, not replace, rapid reductions in fossil-fuel emissions and other greenhouse gases. With strong MRV, locally appropriate management and farmer-centred governance, soil carbon can become part of a broader and more durable climate solution.

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Volume: 06 Issue No: 10

MICROBIAL ACTIVITY AND ORGANIC CARBON RESOURCE MANAGEMENT IN LONG-TERM EXPERIMENTS

Article ID: AG-VO6-I10-111

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Abstract

Soil organic carbon (SOC) is the energy source for soil microbes, and microbes in turn decide whether carbon is stored or lost as CO. Long-term experiments (LTEs) such as Rothamsted's Broad balk and the All India Coordinated Research Project (AICRP) on Long-Term Fertilizer Experiments in India are the only platforms where this two-way relationship can be watched across decades. This article explains, in simple terms, how organic carbon inputs (farmyard manure, crop residues, green manure, compost) and mineral fertilizers shape microbial biomass, enzyme activity and respiration, how researchers measure these changes, and what the evidence says about managing organic carbon resources for soil health, productivity and climate mitigation. It closes with practical lessons and research gaps useful to postgraduate students.

Keywords: soil organic carbon; microbial biomass carbon; soil enzymes; long-term fertilizer experiment; carbon sequestration; farmyard manure; integrated nutrient management; soil health

1. Introduction: The soil as a living carbon bank

A handful of fertile soil holds more living organisms than there are people on Earth. These organisms, mostly bacteria, fungi and archaea, make up only 1–5% of soil organic carbon, yet they run almost every nutrient cycle. Without a steady supply of carbon, the microbial community starves, enzymes fall silent and nutrient release slows. Soil organic carbon is therefore both a *product* of biological activity and the *fuel* for it.

Over a single cropping season it is hard to see how a management practice changes this balance, because SOC changes slowly and seasonal weather masks the signal. This is why long-term experiments, running for 20, 50 or even 150+ years on the same plots, are often called the 'libraries' or 'time machines' of soil science (Johnston and Poulton, 2018; Powlson et al., 2011).

2. What is a long-term experiment?

A long-term experiment is a field trial with fixed treatments, replicated plots and a consistent cropping system maintained for several decades. Three features make LTEs special: (i) treatment effects accumulate and become statistically detectable; (ii) archived soil and plant samples allow new methods to be applied to old material; and (iii) they capture rare weather events and slow processes that short trials miss.

- **Broadbalk, Rothamsted (UK):** winter wheat since 1843, comparing farmyard manure (FYM), mineral NPK and unfertilized control.
- **AICRP-LTFE (India):** started in 1970s at centres such as Ludhiana, Pantnagar, Barrackpore, Jabalpur, Bangalore and Ranchi, testing NPK, FYM and combinations under rice, wheat, maize and groundnut systems (Swarup et al., 2000; Manna et al., 2005).
- **Regional LTEs:** rice–wheat, maize–wheat–cowpea and rice–berseem systems have supplied much Indian evidence on carbon pools (Purakayastha et al., 2008; Majumder et al., 2008).

3. How organic carbon and microbes interact

Carbon entering the soil as roots, residues or manure is first consumed by microbes. A part is respired as CO; a part is built into microbial cells; and the remainder of microbial products and necromass can binds to mineral surfaces or be trapped inside aggregates, where it persists for decades. Modern thinking stresses that stable SOC is formed largely through this microbial 'conversion' route and is protected by association with clay and metal oxides, rather than persisting simply because the original plant material was chemically resistant (Cotrufo et al., 2013; Lehmann and Kleber, 2015). Management therefore matters at two levels: **how much** carbon is supplied, and **what quality** it has. Nitrogen-rich, easily decomposed inputs such as green manure feed microbes quickly, while lignin-rich straw or compost builds slower, more stable pools. Soil texture, climate and moisture determine how efficiently the microbes use these inputs (Kallenbach and Grandy, 2011).

4. Indicators of microbial activity used in LTEs

Soil scientists do not count microbes one by one. Instead, they use integrative indicators, many of which are standard laboratory exercises for M.Sc. students.

Indicator	What it tells us	Common method
Soil organic carbon (SOC)	Total carbon reservoir; long-term trend	Wet oxidation (Walkley and Black, 1934) or dry combustion
Labile / oxidizable C fractions	Early, sensitive signal of management change	Graded-strength $KMnO_4$ or H_2SO_4 oxidation (Blair et al., 1995)
Microbial biomass C (MBC)	Size of the living microbial pool	Chloroform fumigation–incubation or fumigation–extraction (Jenkinson and Powlson, 1976; Vance et al., 1987)
Basal soil respiration	Overall microbial activity (CO_2 evolved)	Alkali trap incubation and titration
Metabolic quotient (qCO_2)	Respiration per unit biomass; microbial stress or efficiency	Respiration ÷ MBC (Anderson and Domsch, 1990)
Enzyme activities	Potential for C, N, P cycling (dehydrogenase, urease, phosphatase, β-glucosidase)	Colorimetric assays (Dick, 1994)

5. What long-term experiments have shown

i) Organic manure builds carbon and feeds microbes

Across Rothamsted and Indian LTEs, plots receiving FYM consistently hold higher SOC, microbial biomass and enzyme activity than plots receiving only mineral fertilizer or no input. Under Indian conditions, sustained manure or manure plus NPK has typically been the most effective treatment for raising SOC and sustaining yield (Manna et al., 2005; Purakayastha et al., 2008). Manure supplies both carbon and a balanced set of nutrients, so microbes are not carbon- or nutrient-limited.

ii) Balanced mineral fertilizer helps, but not alone

Adequate NPK increases crop biomass, and so root and stubble carbon returns, which can raise SOC modestly. A review of long-term studies found that mineral fertilizer generally increased microbial biomass and activity relative to unfertilized soil, largely via greater plant productivity, whereas long-term nitrogen applied in excess of crop demand or without liming can acidify soil and suppress microbial biomass (Geisseler and Scow, 2014). Imbalanced use (for example, N alone) tends to give the weakest outcomes for both crops and soil biology.

iii) Integrated nutrient management (INM) is a good compromise

Combining 50–100% of the recommended fertilizer dose with organic sources such as FYM, compost, green manure or crop residues sustains yield, improves labile carbon pools and supports microbial functioning at a lower fertilizer cost. This is the principle behind INM and is a leading recommendation from the AICRP experiments.

iv) Carbon pools respond at different speeds

Total SOC may change by only a fraction of a percent in a decade, but labile fractions, microbial biomass and enzyme activities respond within a few years. For this reason they are used as early-warning indicators of soil quality. Over long periods, increases in total SOC also depend on soil type: clayey and aggregated soils protect added carbon better than light sandy soils, where much of the input is simply mineralized (Lal, 2004; Majumder et al., 2008).

6. Managing organic carbon resources: practical principles

- **Add carbon regularly.** SOC reaches a new equilibrium only if inputs are maintained; stopping inputs reverses gains.
- **Mix quality of inputs.** Combine fast-decomposing materials (green manure) with slow ones (straw, compost) to feed microbes while building stable carbon.
- **Use residues, do not burn them.** Residue retention returns carbon and nutrients; burning wastes both and harms surface microbial communities.
- **Balance nutrients.** Microbes need N and P to convert carbon into biomass; balanced fertilization improves the efficiency of carbon use.
- **Reduce disturbance.** Minimum tillage and cover cropping protect aggregates and moisture, supporting microbial habitat.
- **Monitor both pools and processes.** Track SOC together with MBC, respiration and enzymes, rather than total carbon alone.

7. Why these matters for climate and food security

Soils hold more carbon than the atmosphere and vegetation combined, so even small changes in SOC are significant. Restoring carbon in degraded cropland can improve soil quality, raise yields and take up atmospheric CO (Lal, 2004). However, sequestration is limited by carbon input, climate and soil type, and it is reversible. Long-term data are therefore essential for realistic estimates, and they caution against over-optimistic claims.

8. Limitations and research gaps for students

- Most LTEs were designed to study yield and nutrients; biological sampling has often started late or been irregular.
- Sampling depth matters: many studies sample only 0–15 cm, which can miss carbon changes in deeper layers.
- Methods differ between centres, making comparison difficult; standard protocols and archived samples are needed.
- Newer tools such as molecular sequencing (microbial community composition), isotopic tracing and microbial necromass biomarkers can be applied to archived soils to link community structure to carbon stabilization.

9. Conclusion

Long-term experiments show that soil carbon and microbial life are partners: organic inputs feed microbes, and active microbes build and cycle carbon. Plots with sustained organic manure or integrated organic plus mineral nutrition hold more organic carbon, a larger and more active microbial community, and more stable yields than plots with imbalanced or no fertilization. For future soil scientists, the lesson is to manage soil carbon as a living resource, to measure biological indicators alongside total carbon, and to draw on long-term data when advising farmers and policymakers on sustainable land management.

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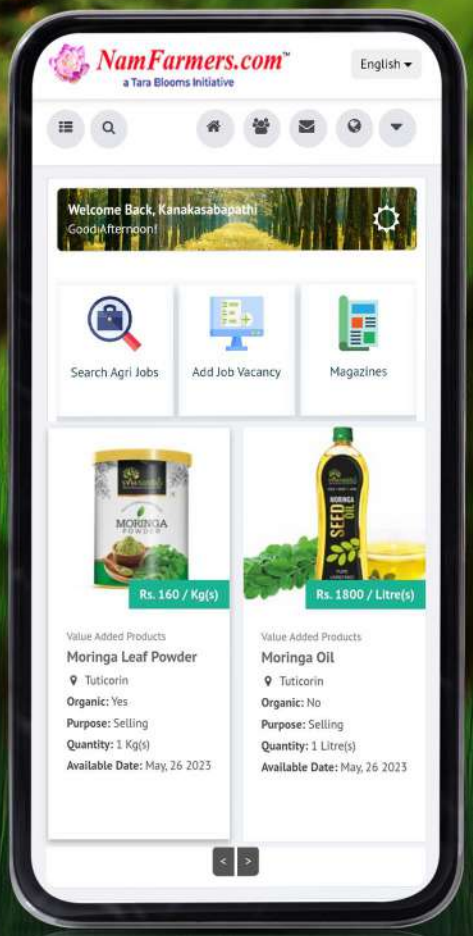
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